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WILLARD HAYES,
U. S. GEOLOGICAL SURVEY
WASHINGTON, D. C.

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State of Connecticut

State Geological and Natural History Survey

BULLETIN NO. 4

THE CLAYS AND CLAY INDUSTRIES OF CONNECTICUT

By

GERALD FRANCIS LOUGHLIN, S.B.

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Preface.

The field work on which this report is based was carried on during the summer vacation of 1903 under the direction of Professor Herbert E. Gregory of the United States Geological Survey, and the laboratory work was done at brief intervals during the following winter. The appropriation for the laboratory work was so limited that no thorough tests requiring special apparatus could be made. The statements made in the text, therefore, are based on what simple tests could be made and on calculations from analyses, and are only approximate.

No research work was attempted in the laboratory. The chapters devoted to the composition and properties of clay are simply reviews of previous work, and are intended to give the reader a general knowledge of the subject.

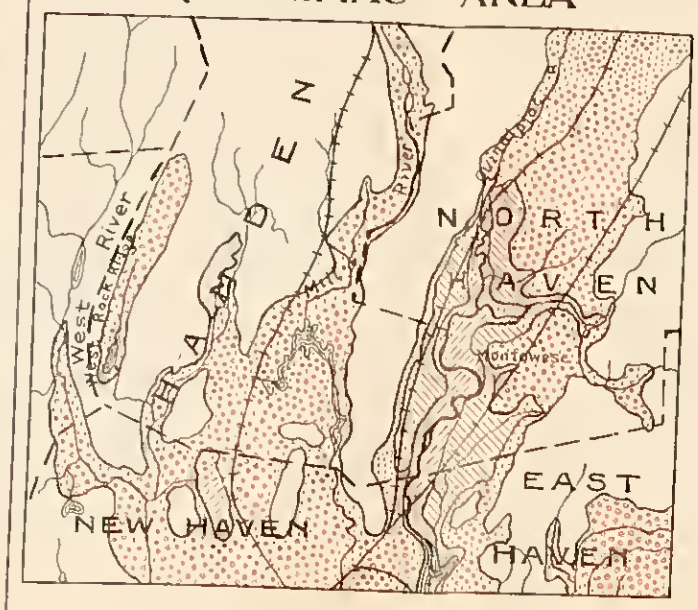
The limited time at the writer's disposal made it impossible to do detailed work, so the report is essentially preliminary in its nature, and could be well followed by one devoted especially to the making of practical tests.

Thanks are due to Professor Herbert E. Gregory and Dr. H. H. Robinson of New Haven, and Professors W. O. Crosby and C. H. Warren of Boston, who gave valuable advice during the work; to Professor W. H. Hobbs of Madison, Wis., who kindly furnished the geological information regarding the kaolin deposits of the western highlands; to the city engineering department of Hartford, and to Mr. C. L. Grant of Hartford, who furnished records of sewer profiles and borings; to the manufacturers who furnished the illustrations of their machines; and to all the clay-working firms in the state who contributed the information asked of them.

Part I

The Clays of Connecticut

QUINNIPIAC AREA



MAP
OF
GLACIAL DEPOSITS
IN
CENTRAL CONNECTICUT

MASSACHUSETTS.

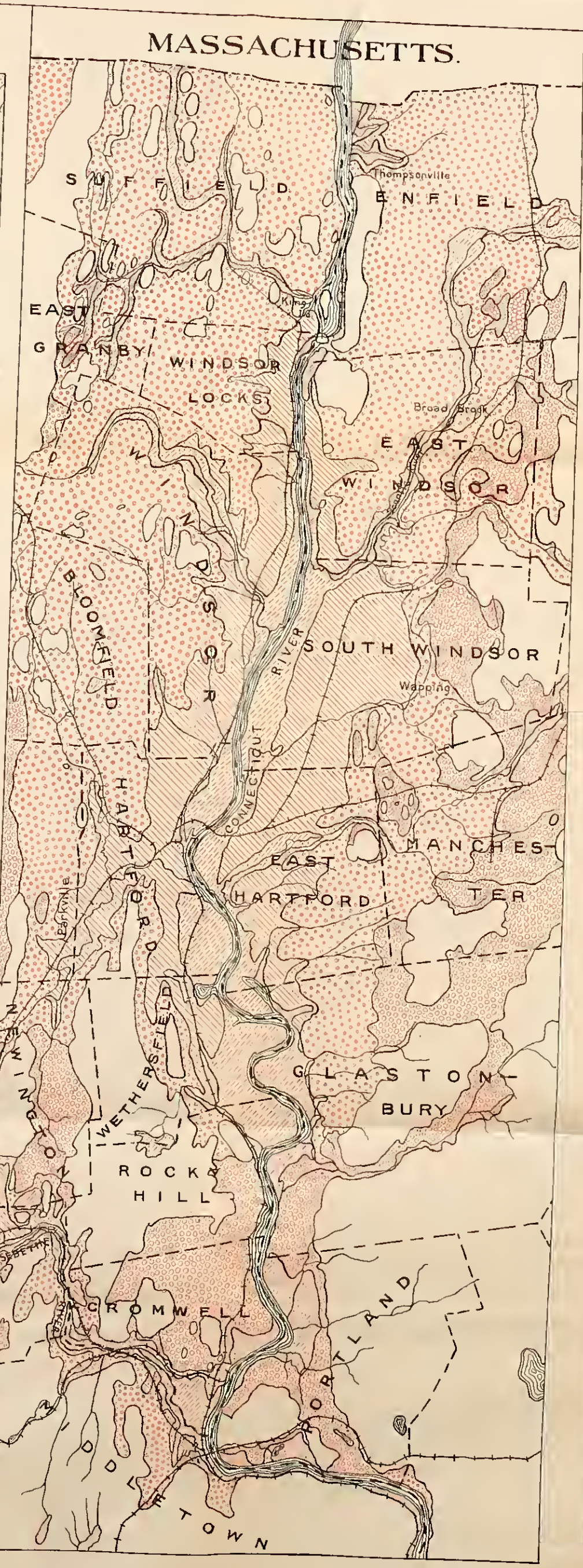
Clay of economic value

Alluvium (Flood plains)

High gravels (kames, deltas, etc.)

Sand.

Till (with outcrops of Bed Rock.)



CHAPTER I.

The Geographical Distribution of the Connecticut Clays.

The clays of Connecticut which are at present being worked are limited to the central, lowland portion of the state, and to West Cornwall in Litchfield County. The clays of central Connecticut occur in level stretches of land between ridges of higher ground. They are often several miles in length and breadth; their height above sea level varies from the neighborhood of 90 feet at the northern boundary of the state to zero at North Haven and Quinnipiac; they are always traversed by rivers or streams, the depth of which below the surface is a very important factor in the drainage of clay pits.

DISTRIBUTION OF BRICK CLAYS.

The distribution of the clays in central Connecticut is shown in the map, Plate I.

Northern Area. — By far the largest clay area in the state is that including the brick yards in and north of Hartford. Examination of stream cuttings, well borings, and sewer profiles shows that the clay is continuous along the valley of the Connecticut River from Wethersfield north to Windsor Locks, probably passes east of the ridge at Enfield, and is continuous with the clay deposit that extends from Thompsonville northward to Springfield and Holyoke in Massachusetts. The width of the deposit varies. At Hartford it lies principally west of the river, and is from four to five miles in width. It then extends northeastward, and, at South Windsor, lies mostly east of the river. The width of workable clay in this neighborhood is from two to five miles. The workable part of the deposit narrows towards the north, and disappears just south of King's Island. From Thompsonville to King's Island the Connecticut River flows over bed rock.

The true extent of the clay east of the river is uncertain.

Detailed study of the region shows that clay, generally in workable deposits, extends along the Broad Brook Valley as far as Broad Brook Village; but the actual extent eastward and northward is obscured by a covering of sand often of great thickness. The nature of the topography, however, strongly suggests that clay underlies at least the western part of this large sandy area, and unites the beds south of King's Island with those at Thompsonville.

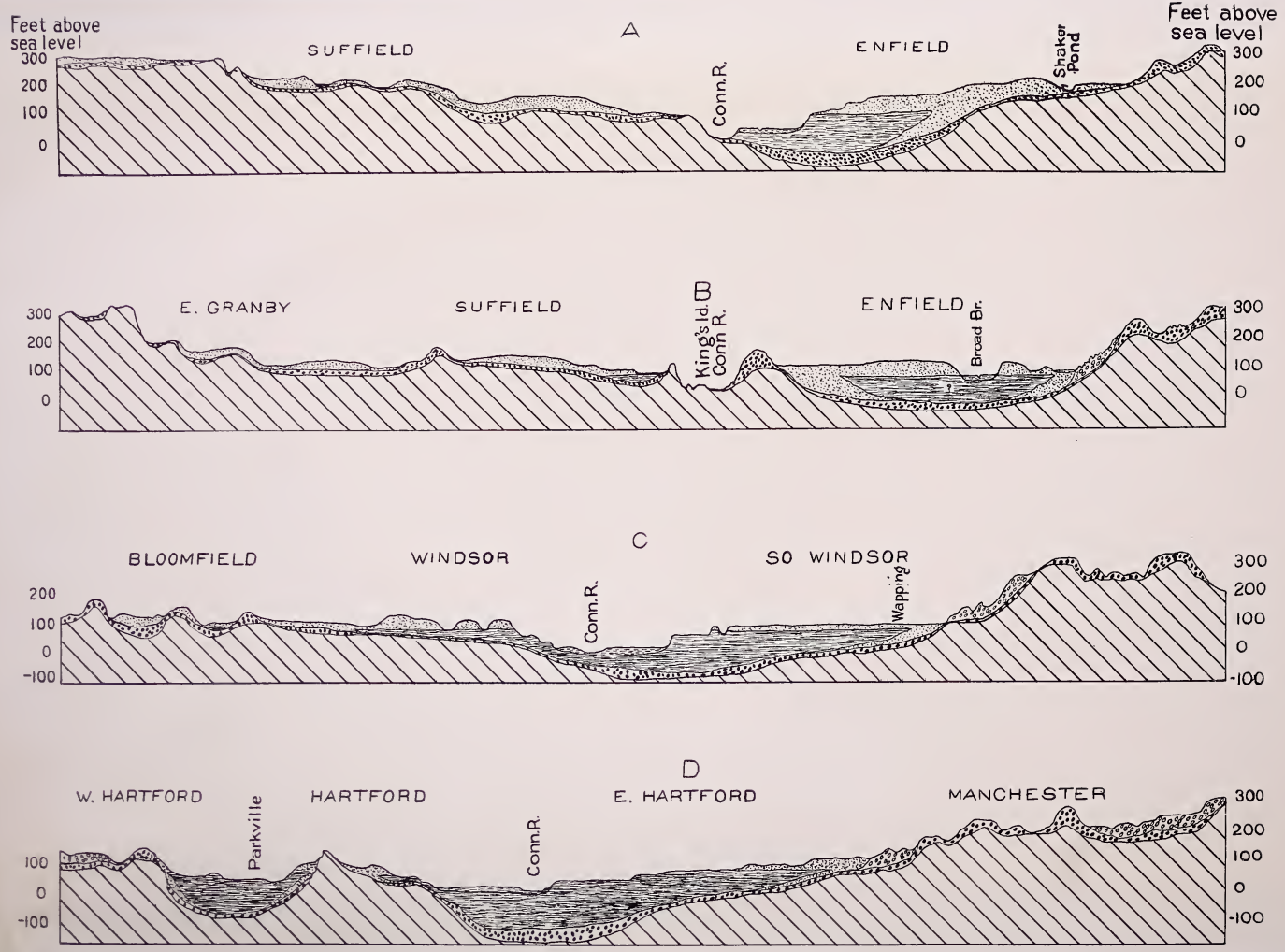
The depth of this large clay formation is also variable, owing to the irregularity of the bed-rock surface. The sections across the deposit shown in Plate II will give the best idea of its depth at different points, and its general extent underground. The data were taken from records of well borings and sewer profiles.

The following are the records of depths obtained: —

Locality.	Depth in feet.
East Longmeadow, stream cuts (blue clay)	20+
Thompsonville, Alden's brick yard (blue clay)	20+
Warehouse Point	0
Windsor Locks (blue clay)	60
Ketch Brook, at road one mile west of R. R. (blue clay)	0 to 5
South Windsor, yard of E. W. Hill Brick Co. (blue clay)	35+
" " Meade & Mullaly's brick yard (blue clay)	30+
Windsor, Elijah Mills & Son's brick yard (blue clay)	30+
" Curtis's brick yard (red and blue clay resting on shale)	18
Bloomfield, (clay and quicksand)	28 to 47
Hartford, Main Street (yellow and red clay)	5 to 12
" Allyn House, Asylum Street (blue clay)	28
" Park Street, at brewery (blue clay)	43
Parkville, Dennis's brick yard (blue clay)	95
Elmwood, yard of Hartford Brick Co. (blue over red clay)	85
" yard of Park Brick Co. (light brownish clay)	95
" Goodwin Bros.' Pottery Works (blue and red clay)	40?
" at railroad station (red clay)	56
" half mile west of R. R. station (clay pinches out under 56 feet of sand).	

(The + sign after figures indicates that the clay extends further for an unknown depth.)

In all these places, save at Parkville, the clay is overlain by a varying thickness of reddish or yellow sand. The clay is usually underlain by hardpan and bed rock, but along the


Feet above sea level
A
SUFFIELD
ENFIELD
Conn.R.
Shaker Pond
Feet above sea level
300
200
100
0
E. GRANBY
SUFFIELD
B
King's Id.
Conn R.
ENFIELD
Broad Br.
BLOOMFIELD
WINDSOR
C
Conn.R.
SO WINDSOR
Wapping
200
100
0
-100
W. HARTFORD
Parkville
HARTFORD
D
Conn.R.
E. HARTFORD
MANCHESTER

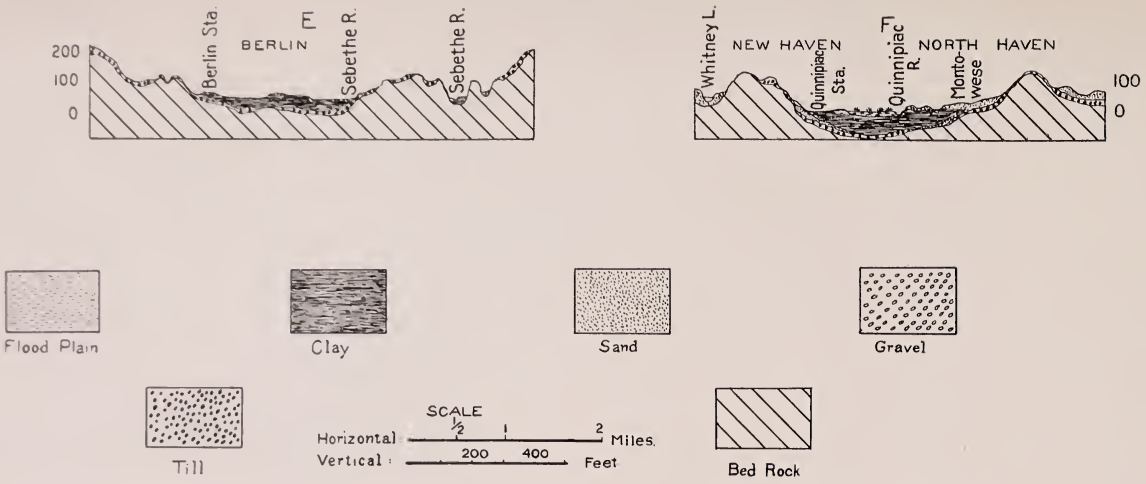


PLATE II. – SECTIONS ACROSS THE CLAY AREAS OF CONNECTICUT.

A. Connecticut valley at northern boundary of state.
B. Connecticut valley at King's Island.
C. Connecticut valley at Windsor.
D. Connecticut valley at Parkville and southern Hartford.
E. Berlin area, along E-W line through Berlin railroad station.
F. Quinnipiac area, along E-W line through Quinnipiac station and Montowese.

margins of the deposit, as at Ketch Brook, it shades downward into sand. The character of the clay is very uniform throughout. It is composed of thin, blue, and sometimes red and blue, layers of very plastic clay, which alternate with layers of very fine quicksand. These layers are generally horizontal, but are sometimes gently undulating.

Clayton Area. — At Clayton, two miles west of Newington Centre, there is a small deposit of reddish clay. Its relation to the other clay deposits to the north and south is not definitely known. The general topography would lead one at first to regard it as the southern extremity of the Connecticut River beds; but frequent low outcrops of red shale exposed along the railroad between Clayton and Newington stations do not favor this view. The character of the clay, furthermore, is somewhat different. It is of a uniform brownish red color, similar to the deposits to the south. The layers of clay and quicksand are often ten inches to a foot in thickness, and, as shown by the sections in the clay banks, lie in long, pronounced undulations, while the surface of the clay is at least 20 feet above that of the deposit to the north, and 40 feet above the surface of the Berlin clay to the south. The clay has been mined to a depth of 15 to 20 feet, but the full depth is unknown. Its actual extent is also indefinite, as it is overlain by a thick covering of coarse sand; but the proximity of trap and sandstone ridges shows that the extent is very limited, while the workable clay is limited to the hillside where the two brick yards of Clayton are situated.

Berlin Area. — The brownish red clay at Berlin is the western extremity of a narrow deposit (of like color) that extends, with one or two probable breaks, along the valley of the Sebethe River to Cromwell and Middletown along the Connecticut River. The surface of the deposit is marked by a nearly level plain, the elevation of which diminishes from 60 feet above sea level at Berlin to less than 40 feet at Cromwell and Middletown. Although the deposit as a whole is horizontal, the layers of clay are often so badly contorted and squeezed together that nearly all evidence of stratification is lost. The clay, as in the northern area, is characterized by alternating layers of plastic, or "strong" clay, and quicksand, but in some

places is of a uniform and comparatively sandy texture throughout. These more sandy places are generally near the boundaries of the area. The thickness of the clay varies, as shown in the section, Plate II, E.

The depths of clay obtained are as follows: —

Locality.	Depth in feet.
Berlin, yard of Berlin Brick Co. (brown clay)	27+
" east of Merwyn's brick yard (brown clay)	60?
Beckley P. O., yard of American Brick Co. (brown clay)	85+
Newfield, Johnson's brick yard (brown clay)	30+

Quinnipiac Area. — The clay deposit of the Quinnipiac Valley extends from North Haven station southward into New Haven. Its width increases from North Haven southward to a maximum of about two miles, where it stretches from the vicinity of Scheutzen Park, New Haven, across the broad, marshy meadow to Montowese. Owing to the marshy condition of the area, which is occasionally covered by flood tides, only the margins of the area can be worked. (See Plate III.) The character of the clay is identical with that of the Berlin area, brownish red in color, generally banded and sometimes contorted, and often sandy near the margins. The clay is usually overlain by three to five feet of peat. The depth of the clay could be ascertained only along the margins of the area. The following records were obtained: —

Locality.	Depth in feet.
North Haven, I. L. Stiles & Sons' brick yard (overlain by more than three feet of yellow sand)	15 to 30
Quinnipiac, Shares's brick yard	6 to 20
" Davis's brick yard,	20+
" Brockett's brick yard	25+

South of Davis's yard, the clay surface drops suddenly, and is overlain by over 18 feet of black mud.

Milldale Area. — The only remaining area where clay is being worked at present is at Milldale. This deposit is in a flat, enclosed valley, and is by far the smallest of all the deposits mentioned. The clay is of the same color as that in the Berlin and Quinnipiac areas, and is of sandy character

PLATE III. — THE QUINNIPIAC CLAY AREA, AS SEEN FROM EAST ROCK, NEW HAVEN.

The brick yards are located along the edge of the flat in the central part of picture. The ponds in central part mark abandoned clay pits.

where exposed; but only one exposure was seen, and that was near the margin, where the clay is naturally more sandy than in the central portion. The depth of the clay at this exposure is 15 feet. No other data were available.

Other Areas. — There are several other areas, of limited extent, where clay may be found; but, as they are all more or less similar to those described above, and are relatively unimportant, and are not being worked at present, further mention of them is unnecessary. Clay was formerly worked at Brooklyn and Wauregan in the eastern part of the state, where limited clay areas occur.

DISTRIBUTION OF OTHER CLAYS.

West Cornwall Kaolin Deposit. — At West Cornwall, in Litchfield County, there is a bed of kaolin, or porcelain clay, which, owing to its unique mode of origin, to be described later, has a larger surface area than any other known kaolin deposit in the United States. It has a length of at least 1,000 feet, a width of over 400 feet, and a depth of over 35 feet.[1] The kaolin is white in color, and of a sandy or granular texture.

Other Deposits. — There is another deposit of kaolin in Cornwall Hollow, which occurs as a vein in the rock, and has been exploited. C. U. Shepard[2] in 1837 stated that there was a bed of porcelain clay covering several acres in New Milford. He also mentioned porcelain clay as being found in Sherman, Kent, and Granby.

There is a deposit of fire-clay, similar in composition to kaolin, about two miles south-southwest of Boardman's Bridge, Litchfield County. This deposit was once worked on a small scale. There may be one or two other deposits of a similar clay in Fairfield County, but they are unimportant, and have not been visited.

1 These figures were taken from a report made on the kaolin deposit in 1901 by Dr. Heinrich Ries for the Kaolin Company of West Cornwall, Conn.

2 C. U. Shepard, Report on the Geological Survey of Connecticut, 1837.

CHAPTER II.

The Origin of Clays.

For a thorough understanding of the properties, value, and uses of clays, a knowledge of what clay is and whence it originated is necessary. The term "clay," as commonly used, is a general name for any plastic earthy material which can be molded into any desired shape. Clay, from the mineralogical standpoint, consists generally of the mineral kaolin, a compound of aluminum and silicon oxides and water, mixed with variable quantities of other products of disintegration and decomposition of rocks. The "clays" of commerce are all composed of a greater or less amount of kaolin mixed with fine particles of quartz and other minerals; and the proportions of this mixture depend upon the mode of origin of the clay in question.

Clays may be divided, according to their origin, into the following classes [1]:

I. Residual, formed by decomposition of rocks in situ.

II. Transported, by
- *a.* Glaciers. Till or bowlder clay.
- *b.* Water. Alluvial, lacustrine, estuarine, and marine deposits, including shales.
- *c.* Wind. Loess (?) and adobe.

I. RESIDUAL CLAYS.

The term "residual" is applied to the material left as *residue* by the decomposition of rocks. All rocks, whether of igneous or sedimentary origin, are more or less subject to disintegration and chemical decomposition, according to the minerals of which they are composed, and the resulting residue is composed chiefly of the insoluble minerals, kaolin and quartz, with more or less red oxide of iron.

1 Other more elaborate classifications of clays have been proposed, consisting of several further subdivisions of the divisions here given; but, as the process of the forming of the clay is similar in all the subdivisions of each class, the classification offered here is considered sufficient.

All eruptive rocks are composed principally of varying percentages of silica, alumina, iron oxides, magnesia, lime, soda, and potash. The following analysis is given as an average chemical composition of granite: —

INSOLUBLE.		SOLUBLE.	
Silica, SiO_2	70.00	Ferrous oxide, FeO	2.50
Alumina, Al_2O_3	14.00	Magnesia, MgO	1.00
Ferric oxide, Fe_2O_3	1.00	Lime, CaO	2.00
Oxides of		Soda, Na_2O	3.50
Titanium, TiO_2		Potash, K_2O	4.00
Zirconium, ZrO_2	1.00		——
Phosphorus, P_2O_5			13.00
	——	Water, H_2O	1.00
	86.00		86.00
		Total	100.00

Rain water, always carrying a small amount of carbon dioxide (CO_2), penetrates into the joints or seams and the cracks which have been made by frost action, and attacks the different minerals. Quartz, or crystalline silica, is undecomposable; the feldspars, consisting of potash, or soda and lime, with alumina and silica, are decomposed, the potash, soda, and lime going into solution as carbonates, the alumina uniting with silica and water to form kaolin, and the surplus silica mostly remaining as additional quartz. The dark constituents, principally mica and hornblende, more commonly become hydrated, and pass over to a dark green mineral, chlorite, a hydrous alumino-silicate of iron and magnesia, and to free quartz, while a part of the soluble constituents pass off as carbonates. If the water contains oxygen in solution, the dissolved iron is oxidized to the insoluble ferric oxide, and remains in the residual clay.

It is readily seen from these reactions that pure clay, or kaolin, practically never exists in nature, and that as a rule only those rocks rich in feldspars and free from dark, iron-bearing minerals, e. g., pegmatite veins and binary granites, can yield a white residual clay. As practically all igneous rocks contain some feldspar, they all can yield a certain amount of kaolin in their residual soil, but only the residual

products of pegmatite veins and occasionally of granites or gneisses have yielded kaolin of commercial importance.

As sedimentary rocks are derived from the disintegrated fragments and residual soils of igneous rocks, they also may contain clay and fragments of feldspar which were carried and deposited by streams before they could be decomposed. The brownstone of Connecticut is such a rock, consisting principally of quartz, feldspar, mica, and red clay cement. Shales are formed principally of fine particles of clay which was derived from residual soils, and, owing to its fineness, was carried by the water farther than the other mineral grains, and deposited in one mass. Limestones may contain a small amount of this clay as impurity. Thus, when sedimentary rocks in their turn are disintegrated and decomposed, they, too, will yield a certain amount of kaolin; but it is, save in the case of shales, generally insignificant. The kaolin at West Cornwall is unique in being the only commercially important deposit derived from a sedimentary rock. Undecomposed shales in many states are allowed to disintegrate and are then ground and used, the process simply returning the clay to its unconsolidated condition. This brief discussion shows that residual clay is rarely pure kaolin, even when decomposition is complete. The amount of true kaolin contained is known as the "clay base."

II. TRANSPORTED CLAYS.

As residual clays are mostly impure, the transported clays, derived from partially decomposed residual material, are naturally still more impure. Transported clays may be formed by three agents, which may act separately or conjointly: namely, glaciers, water, and wind.

A. GLACIAL CLAY OR TILL.

Glacial clay, till, bowlder clay, or hardpan, all different names for the same thing, is limited to the northern part of the country, and, commercially, is unimportant, especially in New England. During the Quaternary age of geological history the northern part of North America was elevated far above its

present level, the temperature was colder, and conditions favored a vast accumulation of ice several thousand feet thick in the region near Hudson's Bay. The ice, pressed out laterally at the base by its own weight, began to flow in all directions in the form of a great sheet, covering the whole of Canada, and the United States as far south as Long Island.

The surface of this region heretofore had consisted of decomposing rock and residual soil. The advancing ice sheet scraped away this loosened material, ground the rock fragments to a powder, which it used as an abrasive for grinding down and polishing the surface of the underlying bed rock. This mixture of fresh and decomposed material from different kinds of rocks was spread as a blanket over the surface of the country, varying in thickness from 0 to 50 feet, according to the contour of the bed rock surface. Rock ridges were left nearly bare, while the valleys were filled to a considerable depth. At various points resistance to the advance of the ice, such as a projecting ledge, caused the deposition of unusually large amounts of material, which the ice rode over and left as smooth, lenticular hills. These hills form the so-called drumlins or "hog-backs," so common in central Connecticut.

Till, from its origin, must consist not only of true clay, but mostly of more or less undecomposed rock material, partly reduced by grinding action to a fine powder, or "rock flour," and partly in fragments varying in size from mere pebbles to large bowlders. The aproximate percentages are gravel 25 per cent., sand 20 per cent., rock flour 40 to 45 per cent., and true clay less than 12 per cent. The chemical composition of course depends upon the composition of the rocks from which the material was derived.

B. CLAYS TRANSPORTED BY WATER.

All clays transported by water are derived from rock fragments, residual clay, or till, according to the formations through which the waters depositing the clay pass. The finest particles are only deposited where the water is deep or stagnant, as in alluvial or flood plains, swamps and marshes, lakes and estuaries, and in the deeper off-shore portions of the ocean.

1. *Alluvial Clays.* — The alluvial or flood plain of a river

is the flat, sometimes swampy, area through which it flows for a part of its course, and which is submerged in time of flood. As the water at first sweeps over the plain, it deposits only its coarser material; but, as the water spreads and flows more and more slowly, finer sediment is deposited, and last of all the finest particles are deposited in quiet water. This succession is repeated with every flood, gradually raising the level of the river valley; so alluvial clays are a mixture of sand, clay, and decayed organic matter, the latter resulting from the vegetation growing on the plain or from the sticks, leaves, etc., brought from the flood. The fire-clays of the Coal Measures have an origin analogous to that of alluvial clay, and their light color is due to the presence of vegetation, which, while growing, derived alkalies and lime from the clay, and, while decaying, reduced the iron to the soluble form which was removed by water.

2. *Lacustrine and Estuarine Clays.* — The clays deposited in lakes and estuaries are alike both in character and mode of formation. When rivers or streams empty into a body of quiet water, their velocity is checked, and they deposit their coarser materials, while the finest is carried farther and deposited in deep, quiet water. By long continuation of this process the lake bottom gradually rises, while the coarser materials advance into the lake as a delta, covering the clay beds already deposited, and slowly obliterating the lake.

3. *Marine Clays.* — Where rivers empty into the open sea, the fine material is carried out beyond the limit where wave action stirs the water. The dissolved salts in sea water have a flocculating effect on the clay particles, and incite a much more rapid deposition than that which takes place in fresh water. Clays deposited in the ocean are only available when elevated above sea level, generally in the form of shales.

All clays deposited by water, if overlain by a considerable thickness of sediments and compressed by their weight, lose water and become hardened into shale, which requires grinding and soaking to regain those properties peculiar to clay. Shale is a transitional form between clay and slate, the slate resulting from heat and pressure combined, which so alter its structure that it loses the properties of clay.

C. CLAYS DEPOSITED BY WIND — EOLIAN CLAYS.

In the Mississippi basin there is a peculiar deposit of great extent, known as the *loess.* This deposit is believed by some to have been deposited by wind, by others to have been laid down in water, and no explanation has yet given general satisfaction. In the arid region of the southwestern states there are extensive valley deposits of impure clay, called *adobe,* accumulated mostly by winds, which blow the waste of the adjacent mountains into the valleys.

CHAPTER III.

Geological History of the Connecticut Clays.

Pre-Glacial Conditions. — With the general knowledge of the origin of clays gained from the last chapter, it may be of interest to trace in some detail the origin of the Connecticut clays. At the close of the Paleozoic eon of geologic time, Connecticut consisted of an eastern and a western highland of crystalline rocks separated by a long intermontane valley, the valley of the Connecticut River, which extended from northern Massachusetts southward to the sea. During the Triassic era, which followed, the disintegrating detritus from the crystalline rocks was washed by rapid streams into the central valley, forming a deposit of great but unknown thickness. These sediments were coarse or fine, according to the varying conditions of deposition, and finally hardened into sandstone and shale. Their reddish brown color is due chiefly to the red residual clay which coated the grains of rock before transportation, and partly to the ferruginous clay that was deposited along with the grains, partially filling their interstices. While the sandstone was mostly deposited near the sides of the valley, the shale was laid down in the central portion, where its outcrops are now, by disintegration, or weathering, forming a red residual clay.

During the formation of these Triassic sediments, there were intermittent volcanic eruptions, which came up through the sediments and formed the areas of trap rock so common in the valley. The whole of New England was subsequently elevated, and the soft sedimentary rocks suffered extensive erosion, leaving the more resistant trap in ridges. At the same time the crystalline rocks of the highlands were undergoing weathering, and, in places protected from erosion, were being decomposed and kaolinized to considerable depths. It was during this period that the West Cornwall and other kaolin deposits in the western highlands were formed. The frac-

tured character of the feldspathic rocks and the pegmatite veins enabled water to penetrate and kaolinize them to much greater depths than the adjacent, more resistant rocks.

Advance of the Ice Sheet. — Such were the conditions up to the arrival of the great glacier, which covered all New England, and terminated at Long Island. The work of the glacier has already been described, and it is sufficient here to say that all the residual soil of both valley and highlands, save at those places where deep deposits of kaolin were protected by resistant rock, was scraped away and redeposited as till over fresh rock surfaces. The kaolin deposits are in reality only the bottom remnant of deposits once much larger. It is probable that kaolin deposits existed in the eastern highlands, but were destroyed by the glacier.

The till of the highlands, like that all over New England, is of a bluish gray to buff color, and usually forms thin coverings over the rock. It is too full of bowlders to be of commercial value as a clay. The till in the valley is an unusual type. It is reddish brown in color, owing to the fragments of shale and sandstone of which it is principally composed, and which were derived from Massachusetts and northern Connecticut. These fragments, especially those of shale, are, owing to their softness, mostly small pebbles and grains, but some large stones are found, accompanied by bowlders of the Triassic trap and occasionally of quartzite and schist.

Retreat of the Ice Sheet. — A change to a warmer climate, perhaps correlated with a subsidence of the northern part of the continent, now caused the melting and retreat of the ice sheet. The retreat was not steady, but interrupted by a series of halts, which are marked by high deposits of cross-bedded gravel in the form of kames and short deltas, deposited by swiftly moving water among the stranded blocks of ice that fringed the retreating glacier. These deposits, which served as obstructions to drainage from the ice, and gave rise to temporary lakes in which the clays were deposited, occur in the southern part of Cheshire; along a broken line through Middletown, Berlin, and Plantsville; at Rocky Hill, in Wethersfield, through South Manchester, and at Clayton; and in Massachusetts north of Holyoke.

The subsidence of the land gave little or no head for the waters issuing from the ice front, and, in many cases, the deposits formed at ice halts served to dam the channels and hold back the waters. The valley of the Quinnipiac, depressed below sea level, became a long, deep estuary in which the fine clay derived from the material in and under the ice was deposited. This deposition probably began while the ice front was halted in South Cheshire, the coarser material depositing at the ice front and the clay in the Quinnipiac estuary.

The ice then retreated a few miles northward and established a new front which extended through Plantsville, Berlin, and Middletown. At Plantsville the glacial waters were held back by the frontal deposits at South Cheshire, and formed a lake in which the Milldale brick clay was deposited. The gravel and clay along the Connecticut River south of Middletown were formed during this period.

The conditions regarding the next deposits have not yet been conclusively worked out, but the evidence at hand strongly suggests another ice halt at Rocky Hill, where a large gravel plain, the present altitude of which is 180 feet above sea level, was built southward along the Connecticut valley. The high level of this plain suggests that it formed while ice still lingered at Middletown and along the valley of the Sebethe River, as the highest indication of shore line to the south of the plain is only 120 feet above sea level, 60 feet lower than the maximum height of the plain. When the ice disappeared from Middletown and the valley of the Sebethe, the outlet of the waters was lowered to a level which is now 80 feet above the sea, and the lake was formed in which the brownish red clays of Berlin, Middletown and Cromwell were deposited.

The next retreat of the ice was from Rocky Hill into Massachusetts, and the glacial waters, held back by the kames and high gravel plain at Rocky Hill, spread over the entire Connecticut River valley from Wethersfield northward into Massachusetts. The traces of the original shore line are hidden by the vast quantities of sand and gravel that were washed in from east and west, and narrowed the lake. The level of the clay surface, however, is very uniform. It is somewhat above the 80 foot contour line at the northern boundary of the state, and gradually lowers southward, until, south of Hartford, it

is near the 70 foot line. This slight difference may be accounted for, partially at least, by the depression of the continent to the northward at that time.

There is evidence of a temporary channel extending from Newington station, southward along the Hartford division of the Consolidated Railroad to the lake bed at Berlin. This channel probably formed the outlet of the great lake until the re-elevation of the land, and connected this lake with the Berlin lake, the waters finding their final exit along the Sebethe valley and through Middletown. The channel shows remnants of shore lines at, or a little above, the 80 foot contour, and the slight difference of from 10 to 15 feet between this line and the surface of the clay south of Hartford, shows that the great lake was nearly filled with sediment at the time of its final draining.

It is doubtful to which of these two last mentioned lakes the clay at Clayton belongs. From the general topography, it might have formed in a long arm of either lake, but its undulating character and high level destroy all direct evidence. The color of the clay, however, as well as the high gravels which have been built out over it, suggests that it was formed during the ice-halt at Rocky Hill. The undulating character of the clay beds is apparently due to the weight of the thick deposit of overlying gravel, which squeezed the clay from under it and caused the beds beyond to rise and make room for the displaced clay.

Color of the Clays. — The difference in color between the clays of the northern lake and those of the other lakes is very significant. The material included in the ice which stretched over Connecticut was mostly the red Triassic material; that included in the ice north of Holyoke, Mass., was principally the ground-up débris from the older rocks of northern Massachusetts, New Hampshire, and Vermont, as the ice at this point had ridden over only a few miles of Triassic sediments. Clay from these rocks is characterized by its bluish color. The data from borings, which show the clay, especially in the vicinity of Hartford, to become red at depths of from 15 to 20 feet below the clay surface, also coincide with this conclusion, as the ice, while retreating from northern Connecticut, would still be giving up débris from Triassic material, which would

be covered in time by the clay derived from the rocks north of the Triassic area.

Lamination of Clays. — The interlamination of the fine layers of quicksand with those of strong clay was caused by alternations between slightly moving and quiet water. Prof. B. K. Emerson [1] explains this alternation by the successive seasons of melting and freezing. In the warmer, melting season, the water flowed in greater quantity from the ice front, built out deltas which now form the high coarse gravel plains along the margins of the lake basins, carried the finest sand out into deep water and deposited it, while the minute clay particles remained in suspension. In the winter months, when the flow of the waters practically ceased, the clay particles were deposited over the sand, to be covered again by the sand deposited during the next melting season. By noting the number of these alternations, some estimate could be made of the number of years that elapsed during the deposition of the clay beds.

Undulations and Contortions of Clay Layers. — The cause of the undulations and contortions often seen in these clay deposits is generally attributed to a re-advance of the ice sheet. It has been shown by Prof. Emerson that several re-advances took place near Northampton, Mass., as beds of till alternate with beds of sand and clay, the latter compressed and contorted by the pressure of the over-riding ice, and sometimes showing slaty cleavage;[2] but no such direct evidence has been found in Connecticut. In some of the Berlin clay banks, the clay is so highly contorted that the sand and clay layers are all jumbled together. The clay is exposed at the surface, and there is no sign of till. Some great force must have produced such contortions, and it is possible that a short re-advance of ice took place before the deposits marking the Rocky Hill halt were made; but it seems impossible that the later waters from the great northern lake, which entered the Berlin lake at this place, could have had sufficient velocity to erode all deposits which might have furnished evidence.

At North Haven there is a layer of clay about two feet thick, very highly contorted, between considerable thicknesses of undisturbed layers. This instance offers no more satisfac-

[1] Holyoke Folio (No. 50), Geologic Atlas, U. S. Geol. Survey.
[2] Loc. cit.

tory evidence than that at Berlin, and no explanation will be attempted.

The large undulations at Clayton due to the downward pressure of the overlying gravel have already been explained. Slight undulations in clay at the surface are sometimes caused by tree roots which, in growing, push the clay slightly in all directions; but most slight undulations are probably due to the general settling of the clay. The amount of settling would be greatest in the deeper parts, where the pressure from the overlying beds is greatest. Where the floor of the deposit is irregular, the variations in shrinkage will result in slight undulations, or even slight slips or faults. Examples of both kinds have been observed in the Connecticut clays, and it is also noteworthy that these undulations are most pronounced at the surface, and gradually diminish towards the foot of the exposure.

Joints. — Joints, or vertical seams, are also common in some clay banks, especially where the clay is dry. They are caused by the shrinkage of the clay from loss of water, and are analogous to the cracks seen in dried mud. These joints divide the clay into roughly hexagonal blocks, and facilitate mining, especially when the method of "undermining" is employed.

Clay Concretions. — Very often certain layers in clay banks are crowded with concretions of various size and shape, known as "clay-stones" or "clay-dogs." These concretions consist of particles of clay and fine sand cemented together by carbonate of lime. The lime was originally in minute mineral particles deposited along with the clay, which have since been attacked by the carbon dioxide in the water. The lime was dissolved, carried along the more porous layers, and deposited at points where the solution became supersaturated. The normal shape of such concretions is spheroidal, but is modified by the thickness of the layer in which it lies, and the directions from which the lime carbonate is supplied. Several of these concretions sometimes grow together, forming curious shapes. They are still forming. These concretions, when small, are harmless; but when large, and present in great quantity, they may render the clay worthless.

Bowlders and Pebbles in Clay. — It is not uncommon, in working a clay pit, to find pebbles and even bowlders of con-

siderable size embedded here and there in the fine clay. The only plausible explanation of their presence is that they were enclosed in, or carried upon, blocks of floating ice that broke away from the ice-front, and dropped when the ice melted.

Effect of Post-Glacial Conditions on the Clay Deposits. — It has already been mentioned that, during the retreat of the ice, gravels and sands were deposited along the margins of the great northern lake in the form of deltas, and had begun to fill it. These deposits are characterized by cross-bedded layers, which dip from the lake margins towards the Connecticut River, and, at many clay pits, lie directly and abruptly upon the clay. When, after the final retreat of the ice-sheet, the land surface was reëlevated to the north, the streams received greater velocity, and brought greater quantities of gravel and sand into the lake. At the same time, the waters of the lake found a more direct exit over the lowering barrier at Rocky Hill, rapidly cut an outlet channel through the loose gravels there, and soon drained the lake. The Berlin lake, having now lost its supply of water, also disappeared. The Connecticut now resumed its course through the deposits of the drained northern lake, and developed terraces at intervals as it cut its valley deeper and deeper, until it finally developed its present flood plain, while the tributaries which formerly built out the large gravel deposits, now had to cut down through these deposits to keep at the same level as the Connecticut River. These tributaries, too, were able in some cases to develop terraces of considerable height. The formation of these terraces has a considerable influence on the location of clay pits, as those dug into the sides of terraces can be so leveled that they will be self-draining, and save the expense of keeping a pump.

The downward cutting of the larger streams of the region has practically ceased now, leaving the clay area of northern Connecticut as a dissected plain. The draining of the Milldale Lake and other smaller lakes was a similar process to that of the great northern lake, though less interesting. The reëlevation of the land also raised the Quinnipiac clay above sea level. Present conditions show that the coast of Connecticut is now slowly sinking again, and black mud, consisting of fine clay and organic matter, is slowly accumulating in the estuaries.

CHAPTER IV.

The Chemistry of Clays.

Pure clay consists of the mineral kaolin, a hydrous silicate of alumina, which corresponds to the chemical formula $H_4 Al_2 Si_2O_9$, or $2H_2O + Al_2O_3 + 2SiO_2$. Its percentage composition is:

Silica, SiO_2	46.5
Alumina, Al_2O_3	39.5
Water, H_2O	14.0
Total	100.0

There are two varieties of this mineral: *kaolinite,* which crystallizes in white scales with satin lustre, and ordinary *kaolin,* which is partly crystallized and partly compact. The latter variety is always more or less impure, owing to the presence of quartz, iron oxide, and other products of rock decomposition. Kaolin is a soft mineral, scratched by the finger-nail, and has a specific gravity of 2.6. The color of the pure mineral is white, but varies with impurities through yellow, brown, blue, and red. There is also present in practically pure clay a massive mineral, *pholerite,* very similar to kaolin, but sometimes containing as much as 15 per cent. water. No distinction between these minerals is necessary, however, for all practical purposes.

Some residual, and a few transported, clays, as shown in Chapter II, are very free from harmful impurities; but most clays, especially transported clays, are full of foreign matter, some consisting of from two-thirds to three-quarters impurities. The relative proportion of impurities depends, of course, upon the source whence the clays were derived. Glacial clays, for example, in the limestone regions south of the Great Lakes are very high in lime and magnesia; while those derived from the crystalline rocks of New England are high in silica, iron, and alkalies, with often considerable amounts of lime and magnesia.

The physical properties of a clay are so dependent upon its composition and chemical properties, that many of them may be largely discussed in this chapter, and simply reviewed in the following chapter on physical properties. The chemical properties are governed by the mineral and chemical composition. The chemical constituents commonly found in clay are silica, alumina, iron oxides, lime, magnesia, the alkalies (soda and potash), titanic oxide, water, carbon dioxide, various sulphur compounds, and organic matter.

Silica, SiO_2. — Silica is found in all clays, and may occur in three different forms: in the kaolin or clay base, as pure quartz sand, and in the different silicate minerals that occur as impurities in clays. Silica in kaolin needs no further consideration. Though quartz is considered an impurity in clay, it is an essential constituent for the manufacture of many different products. It occurs in small, angular, or rounded, grains. Its chief properties are (1) to diminish the shrinkage and prevent warping and cracking, which is liable to take place in rich or strong clay; (2) to diminish the plasticity, which is often too great in a pure clay for a molded form to retain its shape; (3) to raise the point of fusion, which in many clays would be so low as to render the clay useless. The degree of the influence of free silica depends upon the amount in the clay. Some flint clays in Missouri contain as little as 0.5 per cent. quartz, while the most impure clay from the same state contains 86 per cent.[1] An analysis of New Jersey clay showed only 0.2 per cent.[2] The Connecticut brick clays contain, as a rule, over 50 per cent. silica; the kaolin at West Cornwall 47.50 per cent. Fifty per cent. generally is considered very high.

The fact that quartz is infusible and expands slightly in all directions when heated explains its property of diminishing shrinkage. Thus a large percentage of quartz means a low precentage of shrinkable material, while the actual amount of shrinkage is in part counteracted by the expansion of the quartz. Addition of a sufficiently large amount of quartz to clay has been known to cause expansion during burning.[3] Of

1 Geol. Surv. of Missouri, Vol. XI, 1896, p. 49.
2 Geol. Surv. of New Jersey, 1878, p. 273.
3 Geol. Surv. of Michigan, Vol. VIII, 1900 to 1903, p. 11.

course, the less the shrinkage, the less the danger of warping and cracking.

When clay is burned, the other impurities, particularly the alkalies, fuse at a comparatively low temperature, and form a cement which binds the infusible grains of sand together into a firm, compact mass. Silica fuses at about 2,800° F., a point somewhat lower than the fusing point of pure kaolin; but 2,800° F. is a higher heat than most refractory clays have to withstand. Silica, however, in large amounts, and in the presence of free bases, as alkalies, lime, or a considerable quantity of iron, tends to form with them fusible silicates, which lower the fusing point of the clay.

Silica in grains of silicate minerals plays a passive part, as these minerals have special fusing points. These fusing points range from the vicinity of 1,900° F. upwards, and are all below the heat that a fire-clay should withstand. Below their fusing points, these mineral particles behave the same as quartz by diminishing shrinkage and plasticity; above their fusing points they act as fluxes.

Alumina, $Al_2 O_3$. — Alumina, besides being an essential constituent of kaolin, occurs in grains of feldspars, micas, hornblende, pyroxene, and the alteration products of these minerals. Its properties, therefore, depend upon the properties of the minerals containing it. It is, however, safe to assume that clays high in alumina are refractory, unless the percentage of fluxes is unusually high. Thus the Connecticut brick clays, though carrying from 17 to over 22 per cent. alumina, are very high in fluxes (15 to 19 per cent.), and are easily fusible; while the kaolin at West Cornwall, with 37.40 per cent. alumina and only 2 per cent. fluxes, is very refractory.

Iron Compounds. — Iron may justly be called the most important impurity in clay, as its presence or absence is the principal factor in determining the use of the clay. Iron oxides exist in nearly all clays, and range from less than 1 to 15 per cent. and perhaps higher. Iron in clay occurs in a number of minerals, either in the protoxide state (FeO), or the sesquioxide state ($Fe_2 O_3$). The protoxide is found principally in magnetite, ilmenite, siderite, in unaltered, and sometimes in altered, ferro-magnesian silicates; the sesquioxide in hematite and

limonite, which may occur alone or as minute specks in altered silicates. Most of these minerals in the clay are in fine grains; but limonite, the hydrated sesquioxide, generally forms a film around grains, or becomes closely united with the kaolin, in either case giving the clay a brownish color. Siderite, the carbonate, occurs in concretions, similar to clay-dogs, and is known as "clay-iron-stone."

The chief property of iron in clay is its influence on the color of both raw and burned clay. Many clays when mined are of a black, blue, or grayish color, due to the protoxide, with perhaps some organic matter, while others are yellow, brownish, or reddish, owing to the sesquioxide. Clay banks are often of yellowish or buff color near the surface, and bluish or gray below, the difference being due to the superficial oxidation of the protoxide to sesquioxide. The presence of the protoxide in burned clay gives rise to a dark gray to black color, often seen in the sagged and partially melted bricks in the arches of kilns; the sesquioxide gives the burned clay a salmon to deep red color; the depth of the color in each case depending on the amount of the oxides present and on the degree of burning.

It takes only a little iron to influence the color of a burned clay. Chinaware clays should contain less than 1 per cent. Clays with less than 5 per cent. will burn to a distinct, but not deep red; while clays carrying from 5 to 8 per cent. give a deep cherry-red color. Higher percentages than this do not increase the redness to any appreciable extent. It matters not whether the iron in the raw clay is in the ferrous (protoxide) or ferric (sesquioxide) state; for, if properly burned, with free access of air, the iron will all finally take the form of the anhydrous red oxide. If, however, there is not free access of air, or the flame is smoky, no iron is oxydized, but the ferric oxide, Fe_2O_3, is reduced to ferrous, FeO, turning the burned clay black. Too much heat, or enough to begin to fuse (vitrify) the clay, also begins to reduce the iron. This is what takes place in the half-melted, black bricks in the arches of scove kilns, although the black color may be intensified by fine cinders and smoke which stick to the burning clay.

Besides influencing the color of clay, iron is an important

fluxing agent. Ferric oxide, on account of its higher fusing point, is not as strong a flux as ferrous oxide. Just how much iron is detrimental to a refractory clay has been a disputed question. Some of the most refractory clays known average over 2 per cent., but refractory clays, as a rule, should not carry over 2 per cent.[1]

Iron, when alone, has been found, according to some writers, the least fusible of the usual impurities; but its fluxing powers are increased by the presence of the other bases. According to other writers, iron is a stronger flux than lime or magnesia. In the tests on the New Jersey clays, samples containing different proportions of iron and potash were fused; and the iron, when exceeding 2.5 per cent., appeared to be more detrimental to refractoriness than did the potash.[2] Clays containing 5 to 15 per cent. of iron fuse at much lower temperature than do other clays, and large excesses of ferric oxide tend to cause blistering in burning,[3] probably on account of the formation of steam from the chemically combined water.

The sulphide of iron, *pyrite* or *marcasite,* the sulphate, *melanterite* or *copperas,* and the carbonate, *siderite,* deserve special mention. Pyrite may occur as nodules ("sulphur balls"), as cubic crystals, or as fine grains disseminated throughout the clay. It is a strong fluxing agent, and is readily decomposed when heated, the sulphur burning to a gas, and the iron becoming ferrous oxide, a strong flux. Sulphur balls are detrimental, as they would cause fluxing in certain spots, while the escaping sulphur gas, SO_2, would unite with more oxygen and water, forming sulphuric acid, which would act on some of the constituents, forming sulphates. These sulphur balls, or sulphur stones, if large, can be removed during preparation of the clay, or, if small, may be crushed in a disintegrator, and disseminated throughout the clay during tempering. When small crystals or grains are not crushed, they produce little black spots of fused iron silicate, such as are often seen in firebrick. Some of the New Jersey clays used in Connecticut for

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1 E. Orton, Jr., Ohio Geol. Surv., Vol. V, 1884, p. 654.

2 G. H. Cook, Geol. Surv. New Jersey, Rep. on Clays, 1878, p. 303.

3 H. Ries, Geol. Surv. Michigan, Vol. VIII, 1900 to 1903, p. 10.

the manufacture of stoneware and fire-brick must be crushed before using to break up the small pyrite crystals.

Pyrite in clays only exists where it has been reduced from the sulphate of iron by organic matter, and where oxidizing agents are absent. Such conditions are practically limited to the fire-clays, especially of the coal-bearing regions. In other clays, for example those in Connecticut, what may have originally been pyrite while in the parent rock, has long since been oxidized either to the sulphate, or, more probably, to the hydrous oxide, limonite.

Iron sulphate can be detected by its characteristic inky, astringent taste. It causes a white efflorescence, and, if in considerable amounts, renders the clay worthless.

Siderite ("clay-iron-stone"), the carbonate, occurs as concretions similar in origin and structure to the "clay-dogs." As was the case with pyrite, it is decomposed by heating, forming ferrous oxide and carbon dioxide. The concretions, if large, should be removed, as their effect on the color and fusibility would be similar to that of pyrite nodules, and the escaping gas would blister the ware. When in small concretions, well disseminated, the carbonate is not harmful.

Lime, CaO. — Lime is also of great importance as a coloring and fluxing agent, especially in limestone regions, where the glacial clays are very high in lime. Lime occurs as carbonate in ground fragments of limestone and in "clay-dogs," and in several silicates, especially the plagioclase feldspars and ferro-magnesian minerals. Lime, in either state, burns to a pure white color, and, when in sufficient amount, neutralizes the coloring effect of iron, by forming with the latter a double silicate which produces buff and cream-colored effects common to many clays of the Great Lakes region. The proportion of lime to produce this neutralization should be at least three times as great as that of iron. Some clays of the Great Lakes region contain as much as 25 per cent. lime, but high grade clays should have less than 2 per cent.

Although the carbonate of lime is fusible only at very high temperature, it readily loses its carbon dioxide, and can then unite with free silica. If sulphur is present and has formed sulphuric acid, the acid will react with lime carbonate, forming

lime sulphate, which is soluble, and will cause efflorescence on the raw, or on underburned clay, if the temperature is not sufficient to decompose the sulphate. As little as 0.1 per cent. of the sulphate is sufficient to cause efflorescence.

This efflorescence can be avoided by mixing thoroughly with the clay a proper proportion of barium chloride or carbonate, the former as a solution, the latter, which is insoluble in water, as a very fine powder. The reaction which follows gives insoluble barium sulphate and lime carbonate.[1] For every gram of lime sulphate there should be added 1.45 grams of barium carbonate, or 1.53 grams of barium chloride, with a little excess for safety. Thus, to a pound of clay containing 0.1 per cent., or 0.4 gram, of lime sulphate there should be added 6 or 7 grams of barium carbonate, or 7 grams of barium chloride. With barium carbonate at 2½ cents a pound, and a green brick weighing 6 to 7 pounds, the cost per 1,000 brick would be increased by about $2.50 (not counting any extra labor of mixing, etc., which could be done directly in the pug mill). Barium chloride would increase the cost only 32 cents per 1,000, and gives a quicker reaction. This process, adequate for other soluble sulphates, would increase the selling price, but would insure a permanent red color.

If an underburned brick still contained any lime carbonate, and was permeated by water carrying carbon dioxide, as all rain water, especially in large cities, does, the carbonate would suffer solution, and be redeposited as a white coating on the surface. Proper handling of the clay and thorough burning should expel all the carbon dioxide, and allow the lime to flux with the silica.

"Clay-dogs" are not harmful in thoroughly burned ware, unless of large size. Large nodules burn to quick-lime, which takes on moisture from the air, and swells, or bursts, the brick.

Lime is very detrimental to refractory clay. If, however, in a coarse, dense clay, the iron and alkalies are less than one per cent., lime and magnesia may together equal 2 per cent.; but usually they should be less than one per cent.[2]

Clays high in lime and magnesia tend to fuse, or vitrify,

[1] H. Ries, Geol. Surv. of Michigan, Vol. VIII, 1900 to 1903, p. 8.
[2] Wheeler, Missouri Geol. Surv., Vol. XI, 1896, p. 71.

suddenly, and are undesirable where incipient fusion is necessary, as in paving brick. Lime in large amounts diminishes shrinkage during burning.

Magnesia, Mg O. — Magnesia is similar to lime both in its general occurrence and properties, and what has been said of lime is practically true of magnesia. Magnesium carbonate, however, is not commonly found in nodules.

Alkalies, $Na_2 O$, and $K_2 O$. — The alkalies in clay are principally potash and soda; lithia is rarely present, while ammonia is readily absorbed by clay and is largely responsible for its characteristic odor,[1] but is quickly driven off on heating.

The chief sources of soda and potash are the feldspars and micas. These alkalies are present in nearly all clays, varying from a mere trace up to about 10 per cent. They are the strongest fluxing impurities in clay, and are especially desirable in clays used for the manufacture of vitrified ware, since, by fusing at a low temperature, and in feldspars fusing slowly, they cement the grains into hard, dense, impervious body.

According to Wheeler,[2] soda is a stronger flux than potash, but the combination of the two is worse than either alone. Their fluxing power is further increased by the presence of the other bases, which favor the formation of a double or complex silicate. Lithia has properties similar to those of potash, but is too rarely present to be of importance.

The influence of alkalies on refractory clays will be best understood by the following paragraph quoted from Cook.[3] "Opinions differ as to the amount of potash which may be positively damaging in a fire-clay. Snelus states that about one per cent. confers so much fusibility as to render them unsuitable at high temperatures.[4] Bischof found that four per cent. potash in a silicate of alumina without any other bases could be fused at the melting point of wrought iron. . . . Clays containing two to three per cent. of potash are said to stand well at high temperatures. The most carefully made analyses of the more noted and best fire-clays of this country and Europe, do not generally show more than two per cent.

1 H. Ries, North Carolina Geol. Surv., Bull. 13, p. 16.
2 Missouri Geol. Surv., Vol. XI, 1896, p. 148.
3 Geol. Surv. of New Jersey, Rep. on Clays, 1878, p. 295.
4 Jour. of the Iron and Steel Institute, 1875, p. 513.

of potash, and the greater number do not contain one per cent. of alkalies. So far as the clays of this state (New Jersey) have been tried, those which are found to have one and a half to two per cent. and upwards of potash have not proved to be good fire-clays. And yet they are otherwise rich and tolerably pure clays. The potash alone appears to explain their low refractory property."

Alkalies have little or no influence on the color of burned ware, but it is said that their presence in large amount tends to turn the red color produced by iron to a brownish tint. The sulphates and chlorides if present will cause a white efflorescence on raw clay, but fuse at too low a temperature to exist in well burned brick.

Titanic Oxide, TiO_2. — Titanic oxide is generally present in clays in small amount. It is much like silica in its behavior, but is not so refractory. When in large amount, 6 to 10 per cent., it has a distinct fluxing action.

Water, H_2O. — Water in clay is present in two forms, mechanically included, or hygroscopic, and chemically combined. Water in the former condition exists in the clay when mined, but is largely expelled by drying in the air. To this water the plasticity of clay is largely due. Included water is sufficiently abundant in some clays, as in the Connecticut brick clays, to allow them to be ground and molded without previous soaking. When the water has evaporated, the clay becomes hard and brittle, but will regain its plasticity upon addition of water. The loss of this water causes a certain amount of shrinkage, which varies with the richness of the clay. If the drying is too rapid, the surface of the clay will shrink and harden sooner than the inner portion, and crumbling or scaling will result.

In burning clay the mechanically inclosed water is expelled at 212° F., the boiling point of water. If the temperature is too rapidly raised at the start, the outer portions of the clay will become hard and impervious before the water can all be driven from the inner part. The imprisoned water then changes to steam, and the resulting expansion swells or bursts the clay. This is one cause of swelled brick. The first, or "water-smoking" stage of the burning, therefore, should be

very slow to allow all the mechanically included water to escape through the pores of the clay.

The chemically combined water is an essential part of the clay base, as well as of certain other hydrous minerals, as limonite and chlorite, which may be present. This water is only expelled at red heat. When it is driven off, the clay loses plasticity for good. The escape of the chemically combined water may also cause swelling and bursting of the clay unless the temperature at red heat is kept uniform for a time, and then raised very slowly. By the loss of chemically combined water, the platy structure of the clay base is destroyed, the particles become indistinguishable, and the clay becomes a stony mass, which increases in density as the temperature is raised.

Carbon Dioxide, CO_2. — Carbon dioxide is the gas arising from the breaking down of carbonates by heat or the burning of organic matter. The gas itself is harmless, unless present in very great amount or hindered from escaping, when its expansion, like that of steam, will swell or burst the clay.

Sulphur Dioxide, SO_2. — Sulphur dioxide is derived from the oxidation of sulphur from sulphides or from the breaking down of sulphates, which are mostly dissociated at high temperatures. It readily unites with oxygen and steam, forming sulphuric acid, which attacks the alumina and other bases in clay very strongly, and, when in considerable amounts, causes a blistering of the clay. Its action is detrimental only when it is derived from minerals of considerable size. When disseminated throughout the clay, its action is uniform and not noticeable. It may, however, form sulphates which, in clay not burned to the temperature at which they decompose, will in time leach out and whiten the surface of the burned product.

Organic matter. — Organic matter is present in all clays to a greater or less extent, either as decaying vegetable matter at and near the surface, or in fine carbonaceous particles which have resulted from matter deposited in the layers of the clay. It is a strong coloring agent, giving to raw clay colors which vary from gray to black according to the degree of color produced by iron and other coloring agents. The

black mud in the marshes along the coast, and the black color of many slates, is due to organic or carbonaceous matter. Organic matter is easily driven off by heating, and has no influence on the color of the burned clay, unless, owing to an insufficient supply of air, it should reduce the iron and aid in producing a black color. The presence of organic matter in raw clay may so obscure the other coloring agents that it prevents a prediction of the color to which the clay will burn. Thus, while the clay of northern Connecticut, colored blue by ferrous oxide, burns to a deep red, there are some clays, colored blue by organic matter, that burn white.

MINERALS IN CLAY.

The properties of minerals in clay depend upon their structure and composition. All but kaolin and water, that is all the coarser grains of foreign matter, tend to lessen the plasticity. Some finely ground mineral matter possesses a certain degree of plasticity when wet, but it lacks cohesive strength on drying. The chemical properties depend upon the chemical constituents already discussed. It should also be borne in mind that the fusing point of a mineral is often lowered by the presence of other more fusible minerals. Even silica, which alone fuses at 2,800° F., is easily fused at about half that temperature when mixed with an equal volume of sodium carbonate. The fusing point of a clay then, is largely influenced by the most fusible mineral present. It remains only to see a list of the minerals found in clays, with their chemical composition, to gain a general understanding of their influence.

Name	Composition			
	Fluxes	Alumina [1]	Silica [2]	Volatile Matter
Kaolin	.....	Al_2O_3	$2\,SiO_2$	$2\,H_2O$
Quartz	.....	.....	SiO_2	.....
Feldspars				
Orthoclase	K_2O	Al_2O_3	$6\,SiO_2$	.....
Albite	Na_2O	Al_2O_3	$6\,SiO_2$	.....
Oligoclase	$3(Na_2O, CaO)$	Al_2O_3	$6\,SiO_2$) ($2\,SiO_2$	.....
Anorthite	CaO	Al_2O_3	$2\,SiO_2$	.....
Zeolites	CaO, Na_2O, K_2O	Al_2O_3	3 to 4 SiO_2	2 to 6 H_2O
Micas				
Muscovite	K_2O	$3\,Al_2O_3$	$6\,SiO_2$	$2\,H_2O$
Biotite	$K_2O + 2(FeO, MgO)$	$2\,Al_2O_3$	$6\,SiO_2$	H_2O
Magnetite	Fe_3O_4	.....	.....	.....
Hematite	Fe_2O_3	.....	.....	.....
Limonite	$2\,Fe_2O_3$	.....	.....	$3\,H_2O$
Siderite [3]	FeO	.....	.....	CO_2
Pyrite, Marcasite [4]	FeS_2	.....	.....	.....
Calcite [3]	CaO	.....	.....	CO_2
Dolomite	$CaO + MgO$	.....	.....	$2\,CO_2$
Chlorite	$5(Mg, Fe)O$	Al_2O_3	$3\,SiO_2$	$4\,H_2O$
Epidote	$4\,CaO$	$3(Al, Fe)_2O_3$	$6\,SiO_2$	H_2O
Rutile	.....	.....	TiO_2	.....
Ilmenite	FeO	.....	TiO_2	.....
Sulphates soluble in water				
Gypsum	CaO	.....	.....	$SO_3 + 2\,H_2O$
Alum	K_2O	Al_2O_3	.....	$4\,SO_3 + 24\,H_2O$
Epsomite	MgO	.....	.....	$SO_3 + 7\,H_2O$
Sodium sulphate [5]	Na_2O	.....	.....	SO_3
Potassium sulphate [5]	K_2O	.....	.....	SO_3

[1] Including isomorphous Fe_2O_3.
[2] Including TiO_2.
[3] Loses CO_2 at red heat.
[4] Readily burns, giving off S, which oxidizes to SO_2.
[5] Sodium and potassium sulphates usually occur with sulphates of ammonium, calcium, or magnesium as double salts.

CHAPTER V.

The Physical Properties of Clay.

Several of the physical properties of clay, especially plasticity, shrinkage, color, and fusibility, have been already touched upon in connection with the chemical properties, and this chapter is intended to group together the facts already known, and in addition to discuss those properties which are independent of chemical properties. Physical properties may be conveniently grouped under the following headings:

PURELY PHYSICAL.	PHYSICAL AND CHEMICAL.
Structure.	Odor and Taste.
Hardness.	Shrinkage.
Feel.	Color.
Homogeneity.	Fusibility.
Density.	
Fineness of Grain.	
Strength.	
Slaking.	
Plasticity.	

Structure. — The structure and texture of a clay are largely dependent on its origin and consequent degree of purity, and are important chiefly because of their influence on other properties. Kaolin is a more or less compact mass, with no definite structure, such as cleavage or lamination; but clays of sedimentary origin often contain distinct layers of sand alternating with clay, and are well laminated. Many dry clays are jointed into polygonal blocks, which facilitates mining by the undermining method. Some clays are so dry, tough, and hard as to require blasting; others so soft as to be easily dug from the bank with a spade. The chief importance of the structure, then, is its influence on the methods of mining the clay.

Hardness. — Pure, compact kaolin has a hardness of 2 to 2.5; that is, it can be scratched by the finger-nail. Although, when moist, it is soft and generally plastic, the individual par-

ticles nevertheless possess their normal hardness. The hardest mineral impurity in clay is quartz, with a hardness of 7, sufficient to cut glass. The more abundant this mineral is, the harder will be the clay. The effect of hard impurities is felt in the wear of the machinery. The coarser and more siliceous the clay, especially if not soaked, the sooner and more often will the parts of the machine need to be renewed.

When clay is burned, the hardness increases as the clay shrinks. At the point of incipient fusion, when the individual grains have united, it is harder than glass, and, at complete fusion, it is nearly or quite as hard as quartz.

Feel. — The feel of a clay is found by rubbing a moistened piece between the fingers, or the teeth. The fine, pure, and plastic clays have a smooth, slippery feel, while the coarser and more impure clays are more or less gritty. Some very pure clays, however, the flint clays, are not plastic, and lack this greasy feel.[1] The feel gives a rough determination of the coarseness of a clay, its plasticity, and its consequent ability to be molded without cracking. Feel is a rapid method, convenient for out-of-door use, and sufficiently accurate for all practical purposes.

Homogeneity. — Clays vary from a practically homogeneous mass, as in many kaolins, to widely varying laminated clays, with coarse and fine layers. Homogeneity is important only in clays used for finer grades of work, where lack of homogeneity would cause cracking in drying and burning, and irregularities in shrinkage, and would interfere with the molding. In brick clays homogeneity is not important, but in higher grades of work, most clays have to be washed before they can be used.

Density. — The density of a clay depends largely upon the impurities present. The specific gravities of quartz and feldspar, the most common impurities, range from 2.55 to 2.75, while that of kaolin is from 2.60 to 2.63; so their presence does not alter the value of the density of solid matter. The presence of a large amount of quartz will, however, tend to raise the specific gravity, as it has not so strong an attraction for water, and the proportion of solids to water is increased.

1 Wheeler, Missouri Geol. Surv., Vol. XI, 1896, p. 80.

Most superficial clays possess a considerable quantity of water, and have an average density of 2.00 or a little less. The density is largely influenced by the pressure of overlying material which squeezes out the included water. Superficial clays from Missouri range in density from 1.69 to 2.17, with an average of near 2.00, while the potter's and fire clays from the Coal Measures, that have usually been overlain by several hundred feet of rock, range from 2.23 to 2.54, with an average of about 2.40.[1]

The importance of density lies in its influence on the refractoriness. The denser the clay the greater the refractoriness, other things being equal. The tests on the Missouri clays showed that "for every increase of 0.20 to 0.25 in the density of a clay, the fluxing impurities may be increased 0.5 to 1.5 without lowering the refractoriness; and, as clays are liable to range from 1.50 to 2.50 in specific gravity, it is impossible to weigh correctly the evidence of chemical analysis of a clay unless the density and fineness of grain are also given."[2] The influence of density is simply due to the fact that the greater the density, the less is the pore space, and the more difficult is the permeation of the heat. The amount of pressure used in molding bricks should have some influence on the density and fusibility. Bricks molded by the heavy machines would naturally stand more heat than bricks of the same clay molded by the lighter machines.

Fineness of Grain. — Fineness of grain is of considerable importance, though it is not yet fully understood. In clays of the same composition, the finer the grain, the more fusible the clay, as there is a greater surface to receive the heat. For this reason, manufacturers of refractory material take care not to grind their clay too fine. Plasticity, to a certain extent, depends on fineness of grain, but is influenced more by the shape than the size of the grains. Shrinkage was formerly supposed to increase with fineness of grain, but the relation is not uniform, as shrinkage is influenced by other properties as well. Fineness of grain may be estimated by the feel, or by microscopic study, but most readily by the rapidity of slaking.

1 Missouri Geol. Surv., Vol. XI, 1896, p. 91.
2 Loc. cit., p. 91.

Slaking. — Slaking is the property of air-dried clay to fall to a powder when placed in water. It serves readily to detect the fineness of grain, and is also of value in the washing of clays, for, after slaking and stirring, the coarse grains separate and settle rapidly, while the fine material is decanted or siphoned off and allowed to settle.

Strength. — The strength of a clay is closely related to its plasticity. A "strong" or "fat" clay is one that is plastic and can be molded without cracking. This strength is due to the mechanically included water and to the interlocking character of the particles, which, in "strong" clays, occur as thin plates which overlap and slide over one another. On this property depend the tensile and crushing strengths. When clays have been molded and dried, they require a force varying from 20 pounds in lean clays to 300 and 400 pounds in very plastic to pull them apart. This test of tensile strength is an elaborate and accurate way of determining plasticity, but is not of much practical value, as plasticity can readily be estimated by the feel. A burned brick increases in crushing strength with the thoroughness of burning, and completely vitrified bricks have a crushing strength nearly, if not quite, equal to many granites.

Plasticity. — Plasticity is one of the most important properties of clay; still its cause has not yet been determined to full satisfaction. Plasticity has been attributed to various constituents, as the clay base, the impurities, the alumina, the included and combined water, and the platy structure of grains, but no single property can fully account for it. The impurities and the alumina have no direct connection with plasticity. Some impure clays are very plastic; others are not. The same is true of clays high in alumina. The included and combined water, as well as the platy structure, are all directly connected with the plasticity; and, with one of the three missing, plasticity is also absent.

Some clays are plastic when first mined; others require grinding to give them plasticity. When the latter are examined under the microscope, they are seen to consist, not of a compact, amorphous mass, but of bundles of small six-sided plates or scales. These bundles are broken up by grinding,

leaving the separated plates to interlock with one another and form a plastic mass. By long continued grinding the plates are destroyed, and plasticity is largely lost. Wheeler in his tests on the Missouri clays [1] concluded that clays were most plastic when their grains could be passed through sieves ranging between 50 and 100 meshes to the inch; but in the Connecticut brick clays, which are very highly plastic, over 90 per cent. of the material can, after slaking but without any grinding, be passed through a 160 mesh sieve. This fact seems to show that the platy structure can exist naturally in very small particles.

When a lump of plastic clay has dried in the air, it loses its plasticity, but regains it on addition of a sufficient amount of water. The mechanically included water acts as a lubricant, and allows the plates to slide over one another, but still holds them by capillary attraction. Too little water does not render a clay plastic, and too much causes it to slake. The proper amount can be found only by experiment. The finer and more thinly lamellar the clay, the greater is the amount of water required to produce plasticity. Some clays require over 30 per cent. water.

In fine impure clays, grains of quartz and other minerals often make up the greater part of the material; yet there is enough clay base present to give sufficient plasticity. Some clays, such as the Connecticut brick clays, consisting from two-thirds to three-quarters of sand and rock flour, are so plastic that they still require an addition of coarse, sharp sand, before they are stiff enough to hold their shape when molded.

Chemically combined water is the third constituent that has a direct bearing on plasticity. When clay is heated to red heat, this water is expelled, and the plasticity is destroyed for good. Such is naturally the case, as the platy structure belongs to the mineral kaolin, which contains 14 per cent. combined water. When this water is expelled, the mineral, and consequently the platy structure, are destroyed, and the remaining compound has no more plasticity than has any powder when mixed with water.

Other minerals, as micas, chlorite, and gypsum, are hy-

[1] Loc. cit., p. 105.

drous, have platy structure, and when ground possess some plasticity; but none possesses it in so marked a degree as kaolin. Even quartz flour has been found to be slightly plastic when wet; but, like the above minerals, lacks cohesive strength, and can stand but little handling when dried. Clay, even when dried in air for months, possesses from 1 to 2 per cent. of mechanically included water. Clay has a marked affinity for water, and readily absorbs it from a damp atmosphere, retaining it, while other substances lose it. This property, together with the platy structure, seems to account for the plasticity: the included water acts as a lubricant, while the attraction of water around the plates serves to hold them together.

Plasticity is especially important in determining the use of a clay. Plastic clay can be molded into any shape desired, as fancy pottery and china, and will retain its shape while drying. If clays are too plastic, they can be partially dried, or mixed, in lower grades of work, with a proper amount of "grog" (sand, burned clay, etc.) to diminish their plasticity to the desired degree.

Odor and Taste. — The odor and taste of clays depend upon their constituents that are volatile or soluble in water. The common argillaceous odor is readily noticed, especially in damp, plastic clay. It is due to volatile matter, perhaps largely to ammonia, all of which is driven off in heating, and the burned clay has no characteristic odor. Odor, then, only serves to confirm the presence of clayey matter in raw material. The taste of a clay is of considerable importance, as it serves to detect soluble salts that would cause efflorescence.

Shrinkage. — Shrinkage in clay is due to two causes: the expulsion of mechanically included water by air-drying, and of chemically combined water by burning. The more plastic clays suffer the most air shrinkage, as they have the most water to lose. The average amount of shrinkage has been estimated at one-twelfth the volume. Shrinkage in very plastic clays is often uneven, as the wind and sun quickly remove moisture from the exposed surfaces, while the interior of the clay does not allow its water to escape fast enough to supply the surfaces. Thus the surface shrinks rapidly, dries, and may fall away, exposing a new, moist surface. This fact is of great

importance in drying molded clay. Lean, or diluted clays, such as are used for common brick, can be dried rapidly, as their impurities and admixture of grog render them sufficiently porous to give up their water uniformly; but rich clays, used for higher grades of work, must be dried slowly and carefully to prevent cracking.

Shrinkage during burning is due partly to the driving off of what included water still remains in the clay, and partly to the expulsion of the combined water. The included water passes off at the temperature of the boiling point of water, the combined water at red heat. With the expulsion of combined water the clay shrinks to a compact, impervious mass. As was stated in the last chapter (page 37), the heat must be raised very slowly while the waters are escaping, for too rapid heating will entrap some of the water within the clay, which will turn to steam and swell or burst the brick. Large quantities of brick may be spoiled by too rapid heating. The importance of shrinkage is its influence on the size of the molds. They must be of such size that the molded clay, when burned, will have the proper size.

Color. — The color of a clay before burning is of no importance except as an indication of what the color of the burned clay will be. The presence of organic matter may obscure the true color. The color of a burned clay is important in determining the uses to which the clay may be put. The causes of the different colors have been explained under iron and lime, and it is sufficient here merely to state the colors and their causes in the following table:

COLOR OF CLAY.	CAUSE OF COLOR.
A. Before Burning.	
Gray to blue and black	Ferrous iron or organic matter.
Yellow, brown, reddish	Ferric iron in hydrated form.
White	Absence of iron and organic matter.
White efflorescence	Salts soluble in water.
B. After Burning.	
Pale salmon	Small amount of iron, or underburning.
Dark red	Over 5 per cent. of iron, and thorough burning.

Black	Ferrous iron reduced in fusion of clay by smoky flame or insufficient supply of air. Dust and fine cinders that have stuck to surface of clay while hot.
Cream to buff	Little iron present, or excess of lime and magnesia over iron (CaO+MgO : FeO :: 3 : 1).
White	Absence of iron.
White efflorescence	Soluble salts unexpelled.

Fusibility. — The causes of fusibility have already been treated under several different headings. To sum up, fusibility is increased (1) by the presence of fluxing impurities, as alkalies, iron, lime, and magnesia; (2) by diminution of density; and (3) by increase in fineness of grain. The following paragraph, quoted from the report on the Missouri clays,[1] will give a good general idea of the process of fusion:

"On heating a clay beyond red heat, it is found to become harder, to shrink, and to become closer-grained as the temperature is increased. On heating it still farther a point is reached when it becomes very hard, attaining a hardness of 6.0 to 6.5 (easily scratching glass); it has almost completed shrinkage, it has become very strong, and the individual grains can no longer be recognized. This point is called the point of incipient vitrification (fusion). While the clay lacks all signs of fusion and is stiff and rigid at this temperature, it shows sufficient flow or movement of the particles towards one another to obliterate individual grains, and thereby attains greater density, as it has a decided resemblance to being vitrified. On heating the clay from 100° to 300° F. above this point of incipient vitrification, the density is still further increased by a further and final shrinkage; the hardness becomes somewhat greater, or from 6.5 to 7, while the grains are not only completely obliterated, but the fracture is now like that of china or vitrified ware. This point is called the point of complete vitrification, and the clay, still stiff, retains its form and shape, though it shows greater movement among its particles. On heating the clay from 100° to 400° F. higher, the clay begins to warp and sag, slightly at first, but more readily as the heat

1 Loc. cit., p. 130.

is increased, and to swell and blister; while, on breaking, it is found to be more or less vesicular and scoriaceous. This point is called the point of viscous or scoriaceous vitrification, as the particles are sufficiently fluid that chemical reactions begin which give rise to the gas bubbles that cause the clay to swell and give it the vesicular structure; and, although it is too stiff and pasty to become decidedly liquid, it has attained a temperature when it would fail in all the practical applications of a clay."

The fusibility of a clay may be determined by physical or chemical means. The physical methods consist of fusion in a furnace and finding the temperature by means of a pyrometer. There are several kinds of pyrometers, but the kind mostly used in clay determinations is the series of Seger cones. These cones consist of mixtures of kaolin and fluxes, which are mixed in definite proportions and have definite fusing points, 36° F. apart. The temperature of fusion of the clay is the same as that of the cone the top of which has bent over to the floor at the time the clay fuses. Where very accurate work is desired, these cones are unsatisfactory, as the temperature may still be rising while they are bending over; but their determinations of the fusing points of clays are sufficiently close for all practical purposes.

The chemical method is the calculation by formula from the chemical analysis. Several attempts have been made to deduce such a formula, and all are only approximate. Perhaps the most accurate is that of Wheeler,[1] given below, which is intended to express the "fusibility factor," or a numerical value for the relative refractoriness of a clay. The higher the value, the more refractory the clay.

"
$$FF = \frac{N}{D + D^1} \qquad (A)$$

when the clays have the same specific gravity and fineness of grain. In this formula F F represents the numerical value of the refractoriness. N represents the sum of the non-detrimental constituents, or total silica, alumina, water, moisture, and carbonic acid (carbon dioxide). D represents the sum of

1 Missouri Geol. Surv., Vol. XI, 1896, pp. 149, 150.

the fluxing impurities, or the alkalies, oxides of iron, lime, and magnesia. D^1 represents the sum of the alkalies, which are estimated to have double the fluxing value of the other detrimentals, and are hence added twice."

"When the clays to be compared differ in density and fineness, it is necessary to modify formula A by a constant C that will have different values depending on the density and fineness, so that the formula will be

$$FF = \frac{N}{D + D^1 + C} \quad (B)$$

in which N, D, and D^1 have the same value as in (A).

C = 1, when clay is coarse-grained and specific gravity exceeds 2.25.

C = 2, when clay is coarse-grained and specific gravity ranges from 2.00 to 2.25.

C = 3, when clay is coarse-grained and specific gravity ranges from 1.75 to 2.00.

C = 2, when clay is fine-grained and specific gravity exceeds 2.25.

C = 3, when clay is fine-grained and specific gravity ranges from 2.00 to 2.25.

C = 4, when clay is fine-grained and specific gravity ranges from 1.75 to 2.00.

These values of C are only approximate, but are near enough to make comparisons."

The following are a few values taken from Wheeler's tables,[1] and will serve as a comparison with the calculated fusibilities of some of the Connecticut clays:

No. of Sample	SiO_2	Al_2O_3	H_2O	Total N	D^1 Alk.	Total D	Sp. Grav.	Grain	Fusibility			Value of FF from	
									Incipient	Complete	Scoriaceous	A	B
									°F				
Flint clays 7	67.47	19.33	7.73	94.53	1.07	5.14	2.44	very coarse	2250°	2450°	2700°	15.2	13.3
Flint clays 4	53.90	28.85	11.61	94.36	0.85	6.86	2.40	coarse	2200	2400	2600	12.2	10.9
Kaolin 17	72.30	18.94	7.04	98.28	0.42	1.89	1.89	very fine	2200	2400	2600	42.5	15.6
Potter's clay 25	74.02	15.26	3.69	92.97	2.37	5.38	2.37	fine	2100	2300	2500	12.0	10.6
Potter's clay 24	67.76	21.96	8.23	97.95	0.24	2.43	2.45	coarse	2500	2700	2700	46.0	27.0
Brick clays 26	72.00	11.97	6.42	90.19	3.25	10.11	2.17	fine	2000	2200	2300	6.8	5.7
(Loess) 28	73.92	11.65	5.26	90.83	3.13	9.90	1.98	fine	1800	2000	2100	6.8	5.3
Shales 30	54.80	23.73	6.00	84.53	3.80	15.34	2.37	very fine	1500	1700	1900	4.4	4.0
Shales 32	57.01	24.43	7.63	89.07	3.81	11.47	2.39	coarse	1600	1800	2000	5.8	5.5

1 Loc. cit., pp. 150, 151.

CHAPTER VI.

Commercial Classification of Clays.

It is obvious, after a consideration of the various properties of clay, that a strictly geological classification, such as that given in the early part of this bulletin, is of little or no value, save to the geologist or prospector. A classification for the clay-worker should be based upon the composition and properties of the clay, for on them depends the adaptability of the clay for the various uses. As variations in clays are almost unlimited, such a classification can only be general, and the names given to the different types are usually taken from the most important products made from the clay. Thus we have *china clay, pipe clay, brick clay,* etc. Such names, though corresponding to no scientific classification, convey a definite idea to the clay-worker; but some of them, for example, *brick clay,* are general names, and require subdivision, as *fire-brick, yellow brick, paving brick, and common brick,* every name now giving a definite idea of the properties of the clay. Clays have been generally classified as: (1) kaolins, china clays, and ball clays; (2) fire-clays; (3) glass-pot clays; (4) stoneware clays; (5) clays for vitrified wares; (6) terra cotta clays; (7) brick clays of different kinds; and (8) slip clays.

(1) *Kaolins, China, and Ball Clays.* — Kaolins, china, and ball clays are used in the manufacture of porcelain, china, and white earthenware. Their requisite properties are fine grain, homogeneity, plasticity, freedom from iron and fluxing impurities. Most clays of this class require washing or grinding before they are suitable for use, and feldspar and quartz are usually added to make a compound with all the desired properties. The feldspar, fusing before the clay, cements the particles and furnishes the white glaze. These clays should fuse at about 2,350° F.[1]

1 H. Ries, Clays of U. S. East of Miss. R., Prof. Paper No. 11, U. S. G. S., 1903, p. 37.

The analyses of washed kaolins show the following range of constituents: [1]

	Maximum.	Minimum.	Average of 8 analyses.
SiO_2	59.42	45.70	48.98
Al_2O_3	40.61	27.15	35.89
Fe_2O_3	1.77	0.46	0.97
CaO	0.45	Trace to 0.00	0.23
MgO	2.42	Trace to 0.00	0.47
Na_2O+K_2O	2.82	1.10	1.67
H_2O	13.54	8.95	11.42

Clay used in the manufacture of paper must have natural white color and be free from grit. Its other properties are unimportant. Kaolin is the principal type of clay used.

(2) *Fire-Clays.* — The chief requirements of fire-clays are the withstanding of very high temperatures, 2,500° to 2,700° F., and a moderate amount of plasticity. Coarse grain and high specific gravity are important properties. Mixtures of clay are necessary for the best results. Analyses show the following ranges: [2]

	Maximum.	Minimum.	Average of 9 analyses.
SiO_2	74.25	44.20	56.69
Al_2O_3	38.66	17.25	28.40
FeO	1.93	0.46	1.11
Fe_2O_3	2.51	0.74	1.30
CaO	0.50	Trace	0.30
MgO	0.89	Trace	0.36
Na_2O+K_2O	2.69	0.44	1.21
TiO_2	1.78	1.10	1.37
H_2O	13.55	6.30	9.94

(3) *Glass-Pot Clays.* — Clays for the manufacture of glass-pots must be refractory, burn dense, resisting the fluxing action of glass, possess good bonding power, and burn without warping. Very few clays in the United States are suitable for this use, and those used are mixed with an imported German clay.

(4) *Stoneware Clays.* — Stoneware clay is a semi-refractory clay, which molds easily, and holds its shape while burning. It should be fairly free from iron, but should contain

1 Values taken and computed from Prof. Paper 11, U. S. G. S., p. 39.
2 Compiled from Prof. Paper 11, U. S. G. S.

enough fluxing impurities to cause incipient fusion at fairly high temperatures and produce a non-porous ware. Chemical analyses range as follows:[1]

	Maximum.	Minimum.	Average of 8 analyses.
SiO_2	72.10	45.00	64.08
Al_2O_3	38.24	19.08	23.86
Fe_2O_3	1.50	0.96	1.23
CaO	1.70	0.00	0.78
MgO	0.68	0.11	0.40
Na_2O	Trace	0.00	Trace
K_2O	2.42	0.15	1.48
Li_2O (with Na_2O)	0.02	Trace to 0.00	Trace
TiO_2	1.30	0.29	0.46
H_2O	14.80	6.25	7.78

(5) *Clays for Vitrified Wares.* — This class includes such clays as are used for sewer pipe, paving brick, etc., which do not have to withstand high temperatures. Clays of this class should be fine-grained and plastic, and should vitrify at a low temperature, 2,130° to 2,210° F. They should, therefore, be high in fluxing impurities, especially iron and alkalies, but should be fairly low in lime and magnesia, as their presence in great amount would tend to bring the points of incipient and complete fusion too close together. These two points should be 150° to 200° F. apart. The following table of analyses is taken from the Report on the Missouri clays:

	Maximum.	Minimum.	Average.
SiO_2	75.00	49.00	56.00
Al_2O_3	25.00	11.00	20.50
Fe_2O_3	9.00	2.00	6.70
CaO	3.50	0.20	1.20
MgO	3.00	0.10	1.40
Na_2O+K_2O	5.50	1.00	3.70
Loss on ignition	13.00	3.00	7.00

In all three of the above columns, the ratio of iron plus alkalies to lime plus magnesia is over 2:1.

(6) *Terra Cotta Clays.* — Terra cotta and bricks can be made from clays of so widely different character that an average analysis would be meaningless. The greater part of terra

[1] Table compiled from analyses in G. P. Merrill's "Nonmetallic Minerals," Rep. of Nat'l Mus., 1899.

cotta is now made from a mixture of fire-clays, which burn to a buff color at from 2,280° to 2,350° F. The surface color is made by a slip or glaze.[1] Low grade terra cotta is also made from red-burning clays.

(7) *Brick Clays.* — Fire-brick and paving-brick clays have already been mentioned. Other clays serve for making (*a*) yellow and buff building brick, (*b*) common red brick and earthenware, and (*c*) pressed brick.

(*a*) The yellow and buff brick are made from plastic clays high in lime and magnesia, and comparatively low in iron. The clay should not be too easily fused, as the brick is then in danger of warping. Consequently bricks of this type are likely to be comparatively porous and weak.

(*b*) Common red-burning brick clays should contain at least 5 per cent. iron oxides, and preferably not over 8 per cent., as a greater amount simply lowers the fusing point without improving the color. Red-burning clays burn to a dense body at low temperatures, and fuse slowly enough to give, with sufficient care, a hard body of little porosity without sagging. Most brick clays have a large percentage of fluxes, and commonly show incipient fusion at a little over 1,900° F., and should burn hard at a temperature not over 2,000° F.[2] Clays are often too plastic to retain their shape alone when molded, and are diluted with lean or burned clay, or, preferably, sharp sand that is not too coarse.

The percentages of constituents in classes (*a*) and (*b*) are as follows:[3]

	Maximum.	Minimum.	Average.
SiO_2	90.877	34.35	49.27
Al_2O_3	34.00	22.14	22.77
Fe_2O_3	15.00	0.126	5.31
CaO	13.20	0.024	2.017
MgO	11.03	0.02	2.66
Na_2O+K_2O	15.32	0.17	2.768
H_2O (combined)	13.60	0.05	5.749
H_2O (mechanically included)	9.64	0.17	2.505

[1] Prof. Paper No. 11, U. S. G. S., p. 43.

[2] Ibid., p. 45.

[3] Ibid., p. 45.

Earthenware is made from the finer and less gritty brick clays. Plasticity, easy molding, and burning to a porous body without too great shrinkage are the essential properties.

(*c*) Pressed brick is at present mostly made from more or less refractory clays, as the light color produced is popular, and makes a good base with which artificial coloring material may be mixed. Red clays make good enough brick, but the color is at present out of fashion. The requirements for a pressed-brick clay are uniformity of color when burned, and fairly low shrinkage to preserve straightness of outline. Refractoriness and plasticity are not important, though excessive plasticity is undesirable where the stiff-mud process is employed.[1] Typical analyses are similar to those given for common brick.

(8) *Slip Clays.* — Slip clays are clays fusing at a low temperature to a fluid, so that they can be used as a glaze on stone- and chemical ware. Their requirements are exceedingly fine grain, very high percentage of fluxes, and a fairly rapid fusion to a liquid so that they will form a smooth glaze. High percentage of lime and magnesia, especially in form of carbonates, and comparatively low amounts of iron oxides would probably cause this last property. The chemical analysis of the slip clay from Albany, N. Y., is as follows:[2]

SiO_2	58.54
Al_2O_3	15.41
Fe_2O_3	3.19
CaO	6.30
MgO	3.40
Na_2O+K_2O	4.45
Sulphuric acid	1.10
Carbonic acid and water	8.08
Total	100.47

(9) *Other Clays.* — Loess is a fine material, occurring in the Mississippi valley, intermediate between a sand and clay, and is sometimes used for brick-making. Adobe is an impure

1 Prof. Paper 11, p. 44.
2 G. P. Merrill, Rep. of U. S. Nat'l Mus., 1899, p. 335.

clay, largely transported by wind, that occurs in the arid valleys of the southwest. It is mixed with straw and dried, and can be used in that dry climate without burning for building purposes. Fuller's earth is a very fine clay, used, on account of its absorbent nature, to remove grease from clothing. Its other properties are not essential.

CHAPTER VII.

Composition, Properties, and Adaptability of the Connecticut Clays.

There are in Connecticut four kinds of clay deposits: — residual kaolin, Glacial till, red shale, and the lacustrine or estuarine clays of post-Glacial origin. Only the first and last-named of these deposits are of commercial value. The till and shale could probably, by screening and grinding, make good brick; but they would even then not be any better than the post-Glacial clays derived from them, while the cost and labor necessary for preparing them prevents their use. The prepared material would be similar to the post-Glacial clays in composition and properties, and so need not be considered separately.

COMPOSITION AND PROPERTIES OF KAOLIN FROM WEST CORNWALL.

As the West Cornwall kaolin is the residual product of a feldspathic quartzite, it naturally contains a large amount of free silica, or quartz, with small amounts of fluxing impurities which originally existed in the feldspars. The chemical analysis of the washed material, made for the Kaolin Company of West Cornwall, is as follows: —

Silica	47.50
Alumina	37.40
Iron oxide	0.80
Lime	Trace
Magnesia	0.00
Alkalies	1.10
Water	12.48
Total	99.28

This analysis places the clay among the first-grade kaolins of the country. The low percentage of iron permits the pro-

duction of a white body, while the sum of all the fluxes is insignificant. The free silica is almost removed by washing, and the rational analysis shows

Clay substance	99.00
Quartz	1.00
Total	100.00

The washed clay is very white, is rather granular to the feel, and apparently lacks plasticity; but several experiments and practical tests have shown that, when mixed in a body, the mixture is equal in plasticity to that of bodies made from other kaolins. The material is also highly refractory, as its analysis indicates. Its fusing point is somewhat higher than 3,000° F.

The burned clay is very white, and begins to show a mere tinge of yellow, due to the small amount of iron present, when heated to a high temperature such as would be required for the manufacture of china. This iron is associated in most cases either with tiny scales of mica or small quartz grains, which can only be eliminated with considerable difficulty. These qualities adapt the kaolin for use in sanitary ware, wall tile, semi-porcelain china, and wares of similar grade.

COMPOSITION AND PROPERTIES OF THE LACUSTRINE AND ESTUARINE CLAYS.

Both physical and chemical tests show that the different deposits of central Connecticut are all very similar both in composition and properties. They will, therefore, be treated as a group, while separate mention will be made where one clay differs to a noteworthy degree from the others.

COMPOSITION.

A glance at the following analyses of typical samples will show that the clays are very impure. These analyses were made in the laboratory of the United States Geological Survey by Mr. W. T. Schaller under the direction of Dr. F. W. Clarke, chief chemist.

Number	1	2	3	4[1]	5[1]
Silica, SiO_2	52.73	50.33	55.27	58.02	56.75
Alumina, [2] Al_2O_3	22.25	27.06	20.52	17.93	17.54
Ferric oxide, Fe_2O_3	3.14	2.29	5.34	4.89	4.92
Ferrous oxide, FeO	4.55	2.62	1.55	1.24	0.93
Lime, CaO	1.48	1.22	2.21	3.42	4.18
Magnesia, MgO	3.20	3.34	2.80	1.92	2.34
Soda, Na_2O	2.22	1.78	2.82	3.33	3.40
Potash, K_2O	4.28	4.40	3.43	3.06	3.16
Water (loss) at 107° C.	1.12	1.42	1.37	0.99	1.24
Water (loss) on ignition [3]	4.91	5.24	5.06	5.36	6.28
Total	99.88	99.70	100.37	100.16	100.74

[1] Clay tempered with sand.
[2] Alumina includes possible titanium dioxide and phosphorus pentoxide.
[3] Includes carbon dioxide, and possible chlorine and sulphur dioxide.

No. 1, from East Windsor Hill Brick Co., South Windsor, Conn.
No. 2, from Park Brick Co., West Hartford (Elmwood), Conn.
No. 3, from Tuttle Brothers, Newfield, Conn.
No. 4, from Berlin Brick Co., Berlin, Conn.
No. 5, from I. L. Stiles & Son, North Haven, Conn.

Clay Base. — The amount of clay base present can only be approximately estimated, as examination under the microscope shows the presence of feldspar, chlorite, micas, and garnet, all of which contain alumina. In white mica there are three molecules of alumina to one of alkalies, but in black mica and chlorite the alumina is less than the sum of the other bases, so the total number of alumina molecules in these minerals may be considered to equal approximately the total of the other bases. The percentage of water above 107° does not furnish a basis for accurate calculation, as limonite, chlorite, the micas, and possibly some of the zeolites, all contain combined water, and the percentages shown in the analyses include carbon dioxide and probably small amounts of other volatile constituents. Ferrous oxide, magnesia, and lime, may be present both in the above-named minerals, where they replace one another, and also in the form of carbonate; but, as lime is the most likely to occur as carbonate, and the least likely to remain in altered ferro-magnesian minerals, it was dropped from the calculation, the small amount of lime in the silicates roughly

compensating for the other bases in the carbonates. The calculation, therefore, is made on the assumption that every molecule of ferrous oxide, magnesia, and alkalies is combined with a molecule of alumina, while the remainder of the alumina is estimated in the clay base with proportionate amounts of silica and combined water. The results obtained for the clay base, as is shown by the amount of combined water required, are all a little too high, probably because too great a percentage of bases was allowed for carbonates.

		1	2	3	4[1]	5[1]
Clay base...	$Si\ O_2$.....	15.88	21.96	15.83	13.23	12.94
	$Al_2\ O_3$.....	13.49	18.76	13.45	11.46	10.99
	$H_2\ O$.....	4.78	6.64	4.76	4.06	3.89
Total clay base.....		34.15	47.36	34.04	28.75	27.82
Non-fluxing impurities..	$Si\ O_2$.....	36.85	28.37	39.44	44.79	43.81
	$Al_2\ O_3$.....	8.76	8.30	7.07	6.47	6.55
	$H_2\ O$.....	1.25	0.02	1.67	2.29	3.63
Total non-flux. impurities..		46.86	36.69	48.18	53.55	53.99
Fluxing impurities	$Fe_2\ O_3$.	3.14	2.29	5.34	4.89	4.92
	Fe O...	4.55	2.62	1.55	1.24	0.93
	Ca O...	1.48	1.22	2.21	3.42	4.18
	Mg O..	3.20	3.34	2.80	1.92	2.34
	$Na_2\ O$..	2.22	1.78	2.82	3.33	3.40
	$K_2\ O$...	4.28	4.40	3.43	3.06	3.16
Total fluxes.....		18.87	15.65	18.15	17.86	18.93
Sum total.....		99.88	99.70	100.37	100.16	100.74

[1] Clay tempered with sand.

The clay base comprises from about one-fifth in tempered clay to over one-third the whole mass in the unmixed clay, while the greater part is sand and rock flour, which the microscope shows to consist mostly of quartz, with smaller quantities of mica, feldspar, chlorite, and occasionally garnet, all

but quartz containing fluxing impurities. The quartz serves simply as a natural grog for the clay base, while the use of the clay is dependent upon the fluxing impurities.

Iron Oxides. — The iron oxides are present in all the samples, ranging from a little below 5 to over 7.5 per cent. The ferrous oxide predominates in No. 1, a blue clay; the two oxides are nearly equal in No. 2, which has a grayish brown color; while in the other samples, all of brown clay, the ferric oxide is greatly in excess of the ferrous. When it is remembered that clay containing less than 5 per cent. iron oxides burns to a distinct but not deep red, it is evident that the Connecticut clays can only be used where a red color is desirable. Most of the clays contain sufficient iron to give a deep red when thoroughly burned; but sample No. 2, with slightly less than 5 per cent., contains hardly enough to give a deep red. This defect could be remedied by mixing hematite, or red oxide of iron, with the clay when tempering it. One pound of hematite to 100 pounds of clay would improve the color, while two pounds would insure a deep red, increasing the percentage of iron oxides to 6.75 per cent. The hematite should be thoroughly mixed with the clay. Some brick-makers use hematite in molding. The bricks thus get a good color on the surface but it often becomes worn off with much handling, revealing the true pale color of the brick. This addition of hematite would increase the percentage of fluxing impurities, but the total impurities even then would be slightly less than in the other samples; so the quality of the clay would not be impaired for brick-making.

Lime and Magnesia. — The lime and magnesia are also rather high, ranging from 4.5 to over 5 per cent. They are, in all probability, partly present as carbonates, and it is possible that in samples 2 and 5, where they are nearly equal in amount to the iron oxides, they diminish somewhat the coloring effect of the iron. Addition of hematite would also overcome this effect on the color; but, in the case of sample 5, might make the total amount of fluxes higher than is desirable.

Alkalies. — The alkalies are always very high, over 6 per

cent., and their combined effect is greatly to reduce the fusing point. Their high percentage indicates a considerable amount of feldspar grains, which fuse quietly and slowly, so that the fusing clay may become viscous, but not sufficiently liquid to form a good slip clay.

PHYSICAL PROPERTIES.

Structure. — The lacustrine clays are nearly all banded, layers of strong clay alternating with layers of very fine quicksand. At a few clay banks, however, notably those near the edges of the Berlin area, some along the edge of the Quinnipiac, and that at Milldale, the clays are not distinctly banded, but are of fine, sandy quality throughout. They are more thoroughly tempered by nature, often making addition of tempering sand unnecessary.

At several places, especially at Berlin and Quinnipiac, the clay is divided by vertical joints into roughly hexagonal blocks, thus facilitating undermining. The soft nature of the clay permits plowing, which is employed at a few yards where the clay in the bank is too moist for working and has to be partly dried before molding. The horizontal character of the beds adapts them especially to working by benches, especially in the deeper pits.

Hardness. — The clays as a whole are all soft and easily worked; but their highly quartzose character gives them some wearing effect on the machine, varying with the stiffness of the clay.

Feel. — Most of the ten samples tested had an extremely soft, greasy feel when rubbed between the fingers, and showed only very fine grit when ground between the teeth. The samples from Berlin (American Brick Co.) and from Milldale (Clark Bros.) showed considerable grit when rubbed between the fingers, and were comparatively very gritty to the teeth; but even they would be classed as having a greasy feel.

Homogeneity. — The clays in general are not homogeneous, but possess a distinct banded structure. The alternation of layers, however, is very uniform, so that the clay after passing

through the pug mill is sufficiently homogenous for all its possible uses, except where, through carelessness or accident, pebbles are allowed to remain in the clay. If the clays are slaked, then shaken up in water, and allowed to settle for two or three days, a thin layer will settle over the bottom of the vessel, while by far the greater part remains in suspension for several days.

Fineness of Grain. — The clays are all very fine, as the following rapid test shows. Of a quantity put through a 160-mesh sieve, less than 0.5 per cent. of any sample was caught on the sieve, while the greater part passed through a 200-mesh sieve. Such extreme fineness of grain accounts largely for the high plasticity, indicates considerable degree of shrinkage, and serves also to lower the fusing point.

Density. — The high percentage of free silica, feldspar, and iron oxides indicates a fairly high specific gravity, which is somewhat diminished by the fine grain.

Slaking. — As would be expected with such fine-grained clays, all the samples slaked very rapidly. Five minutes was generally sufficient for the slaking to be completed.

Strength. — Merely feeling the clays shows that they are all strong, although the clays above mentioned as occurring near the margins of deposits are comparatively lean. The tensile strength test was not considered necessary for such plastic clays, as the simple feel is sufficient for practical purposes.

Plasticity. — The high plasticity of the clays has already been mentioned. The clays, in most cases, are mined below ground-water level, and contain enough water to make them highly plastic, so that they can be conveyed directly to the machine and tempered without addition of more water. The plasticity is evidently due to the fine grain, the impurities being so fine as not to diminish, and possibly to increase, the plasticity when wet, and the clay base being in sufficient amount to give the desired cohesive strength to the dried material, even when tempered with 30 per cent. of sharp sand.

Odor and Taste. — The argillaceous odor was strong in all the clays. All of the ten samples were tasteless, thus indicating the absence of an appreciable amount of soluble salts; but

the strong argillaceous odor might easily have obscured small amounts of soluble salts. An unpublished analysis, made in the geological department of the Massachusetts Institute of Technology, of a sample from the Quinnipiac clay showed less than 0.1 per cent. of total soluble salts. Flood tides sometimes reach into the Quinnipiac clay pits, and, on evaporation, leave a white coating of salt over the surface. This would add slightly to the fusibility, but would probably cause no efflorescence on the burning clay.

Shrinkage. — As the means for a fire test were not available, no tests on shrinkage were made, since a test on air shrinkage alone would be of no value. It is, however, evident from the fine grain and high degree of plasticity that the total shrinkage is considerable.

Color. — The color of the clays, both before and after burning, needs no further explanation. It is always due to iron, but the red color may be, as shown in analyses 2 and 5, slightly diminished by the effect of the lime and magnesia.

Fusibility. — As was the case with shrinkage, the means at hand were not sufficient to allow physical tests in the furnace; but the approximate fusing points may be calculated from the analyses by Wheeler's formula (A), given on page 49. The fineness of grain and the high percentages of fluxes show immediately that the fusing points will be very low. The results of the calculations are as follows: —

No.	SiO_2	Al_2O_3	H_2O	Total N	Alk. [D]	Total D	Grain	Fusibility Factor
1	52.73	22.25	6.03	81.01	6.50	18.87	Very fine	3.19
2	50.33	27.06	6.66	84.05	6.18	15.65	Very fine	3.85
3	58.02	17.93	6.35	82.30	6.39	17.86	Very fine	3.39
4	55.27	20.52	6.43	82.22	6.25	18.15	Very fine	3.37
5	56.75	17.54	7.52	81.81	6.56	18.93	Very fine	3.34

Comparison with the values selected from the Missouri clays, page 50, shows that the Connecticut brick clays are distinctly more fusible than the lowest value given. That is, they begin to fuse considerably below 1,500° F., and attain complete vitrification considerably below 1,700° F. This remarkably

low fusing point does not detract from their value as brick clays, but is an advantage in that less fuel is necessary than with other clays to produce well burned bricks.

ADAPTABILITY OF THE CENTRAL CONNECTICUT CLAYS FOR VARIOUS USES.

The high percentage of iron and the extremely low fusing points of the clays limit them to uses where red color is desired and refractoriness is unnecessary, i. e., red earthenware, common and hollow brick, and probably paving, or vitrified, and pressed brick. The fusing point is too low to allow their use for red terra cotta, which is generally expected to withstand fairly high temperatures. Drain tile can be, and has been, manufactured from these clays. Their low fusibility suggests that they might make good slip clays, but experiment has proved the contrary, as they fuse too slowly, and give a rough instead of a smooth coating. Comparison of the analyses of the Connecticut clays with that of the Albany slip clay, page 55, shows the Albany clay to contain large amounts of lime and magnesia, largely as carbonates, with comparatively low iron. This is not the case with the Connecticut clays, and the cause seems to lie in the ability of the high lime and magnesia to produce a more liquid fusion, while the more silicious and ferruginous clays become more viscous than liquid. This statement, however, has not been proved.

The clays are adapted to the best quality of common brick at low expense, if handled with a fair amount of care and skill. The percentage of shrinkage is perhaps too great to give the best results for pressed brick; but, if partially air-dried before molding, they should suffice. The chief difficulty with their use for pressed brick is their red color when burned, which is at present unpopular. Their low fusing points favor their use for vitrified wares of low grade, as paving brick and sewer pipe. Their points of incipient and complete vitrification should be, and probably are, sufficiently far apart (150° to 200° F.) to warrant their use; but actual tests of fire, crushing, and abrasion are necessary to prove their adaptability. A possible objection to their use as paving brick would be that

their too complete fusion and extremely fine grain would produce a smooth and slippery surface, or one that would soon wear smooth. This difficulty could probably be avoided by admixture of a sufficient amount of sand, by molding under high pressure, and by care not to raise the heat too high above the point of incipient fusion.

Part II

The Clay Industries of Connecticut

CHAPTER I.

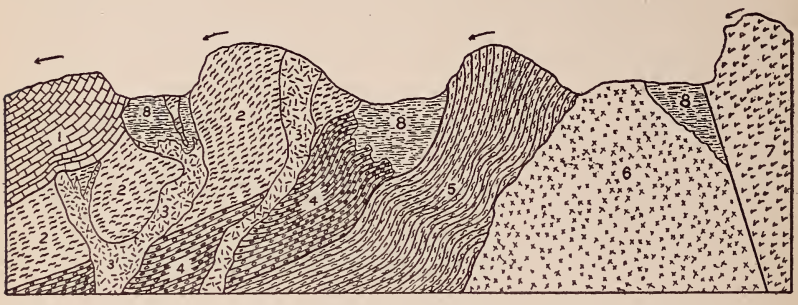
Prospecting: Mining of Kaolin.

The clay industries of Connecticut have included in past years several varieties of manufacture; but at present, besides the mining of kaolin, the only industries are the manufacture of brick, stoneware, and earthenware. These industries will be described in not too great detail, for the benefit of those unfamiliar with them. No descriptions of individual plants will be given, as all are essentially alike, and, with the information given in the following chapters, any further details can be readily seen by visiting the plant in question.

PROSPECTING.

The first and most important thing to know when entering upon any of the clay industries, is the extent and position of the clay deposit; for on these facts should depend the location of the plant. The following brief discussion is intended to give a few general facts that are essential in prospecting. In the country north of the great terminal moraine (that is, throughout New England), residual clays can only be found in valleys protected by a steep slope on the north, which protected them from glacial erosion. In New England, where the transported clays are so abundant and accessible, kaolins are the only residual clays of value. Residual clays from most igneous rocks would be too high in iron to give anything but a red color, and their location in the highlands would prevent competition with the transported clays, which are located mostly along the main lines of railroads. Kaolins of good quality can result only from rocks high in feldspar and very low in dark, iron-bearing minerals, as pegmatites, a few granitic rocks, and rarely, as at West Cornwall, feldspathic sedimentary or metamorphic rocks. Two conditions, then, are essential for finding a kaolin deposit: the country must be rugged, or mountainous, where steep-sided valleys are likely to occur, and a vein of pegmatite, or an exposure of other feld-

spathic and iron-free rock, must be found, which can be followed into one of the steep valleys, protected on the north by a steep slope of hard, resistant rock. These conditions are illustrated by the diagram on this page. When in such a valley a kaolin deposit is found, the extent, both in length, breadth, and depth, should be ascertained, and the plant so erected that the clay may be most easily obtained at as small a cost as possible.



GENERALIZED SECTION SHOWING THREE POSSIBLE OCCURRENCES OF KAOLIN IN GLACIATED COUNTRY.

1 = limestone; 2 = mica schist; 3 = pegmatite; 4 = feldspathic quartzite; 5 = dark gneiss; 6 = light granite; 7 = dark granite; 8 = kaolin, protected from glacial erosion. Arrows indicate direction of ice movement.

The location of transported clays in New England is a very simple matter. Almost any flat area of considerable size, surrounded by high land, is likely to contain a greater or less thickness of impure clay. The nature of these deposits should be borne in mind. They were all formed either in estuaries, lakes, or river floods; and at their margins, where wave action was strongest, and where the coarsest sediments were deposited, only coarse gravels are found; farther from the margin, the gravels shade rather abruptly into sands and clays, which accumulated as long as the lakes existed. The surface of the clay is often covered by a layer of sand, diminishing in thickness towards the middle of the basin, which may hide all the clay from view, except along stream banks. Plate II illustrates the relation of the clay to the other formations.

Whether the clay is covered by sand or not, a systematic series of borings should be made, to show the extent, depth, and character of the underlying clay, and the thickness of the

overlying sand. When these facts are known, it will be possible to erect the plant where the clay is either wanting or of poor quality, or is covered by too great a thickness of sand to allow profitable working. The presence of terraced streams is also a thing to be remembered, as clay pits dug into these terraces can be made self-draining. If poor judgment is used in erecting the plant, the best clay may be covered, and the plant in time will either have to be abandoned or remodeled at a considerable expense and loss of time.

Shales and pre-Glacial transported clays, owing to their folded or tilted character, generally outcrop in belts across the country. Their extent may be found by boring, and by finding their inclination to the horizontal.

MINING OF KAOLIN.

The kaolin at West Cornwall, the only deposit worked at present, is mined by the hydraulic method. A pit is excavated, and a stream of water directed against the sides, washing the material into the pit, where much of the sand settles out. The finer particles still in suspension are pumped up and floated through a thousand feet of troughing into settling tanks, where the finer sand settles. The kaolin is removed from the tanks, and dried in a rotary drier, from which it is elevated and conveyed to its respective bins.[1] Hydraulic mining is a very rapid and economical method, as large excavations can be made with only one or two men to direct the stream of water.

There are no works at the present time in the state that use kaolin, and the product mined at West Cornwall is shipped to large pottery concerns at Trenton and Camden, N. J., East Liverpool, Zanesville, and Steubenville, Ohio, Morristown, Penn., and Maywood, N. Y.

MINING OF FELDSPAR AND QUARTZ.

There is, besides kaolin, a large quantity of feldspar and quartz mined in Connecticut. In fact, Connecticut is one of the chief producers of these materials in the United States.

1 For a detailed description of the washing process, see Bull. New York State Museum No. 35, p. 799, or Prof. Paper No. 11, U. S. Geol. Survey.

The principal producing localities in the state are South Glastonbury and Branchville, though other places have, in times past, produced limited quantities. The "Old Silex" Mine at Lantern Hill in North Stonington has also furnished quartz. Quartz and feldspar are milled near the quarries, and shipped to companies in other states for the manufacture of china, crockery, glass, etc.

PLATE IV. — TERRACE IN CLAY BEDS AT PARKVILLE.

Dennis' brick yard on left. Pits dug into the terrace drain into a small brook which runs across the middle of the picture, in a narrow valley between two terraces.

PLATE V. — DAVIS' CLAY PIT, QUINNIPIAC.

Shows method of working by benches. Left-hand bench is worked out; middle and right-hand benches now being developed. The bedding of the clay is imperfectly shown. Peat overlies the clay.

CHAPTER II.

The Manufacture of Brick.

The manufacture of brick is divided into several parts: (*a*) mining the clay, (*b*) conveying to the machine, (*c*) preparing for the machine, (*d*) grinding, (*e*) molding, and (*f*) burning.

MINING THE CLAY.

The method used in mining the clay depends largely upon the condition of the clay bank — whether deep or shallow, dry or moist. The chief methods, all of which are employed to some extent in Connecticut, are undermining, mining by benches, by plowing, and by steam shovel.

(1) *Undermining.* — Undermining is a simple, but rather dangerous method, generally used only in shallow pits, where the clay is fairly dry. The clay is dug away at the foot of the bank, and wooden wedges are driven in at the surface, two to three feet from the edge, forcing out the mass of unsupported clay, which breaks by falling.

(2) *Benches.* — Mining by benches is adapted to any clay bank, especially where the clay is moist and soft. The process consists in digging with shovels along one level as far as convenience in loading will allow, and then starting a new level about two feet below the first, and so on, until the first level is again brought within reach of convenient loading. By systematic development of these levels, the ground water can be made to collect in one corner of the pit and from there be pumped out, or, in the case of terrace pits, it can be made to flow out of the pit into the stream.

(3) *Plowing.* — Where the clay is too moist for immediate use, or where it requires weathering, the method of plowing is used. The broken lumps of plowed clay are quickly dried by the wind and sun. Only a few yards in Connecticut need to employ this method.

(4) *Steam Shovel.* — The steam shovel is capable of digging large quantities of clay rapidly, one shovelful filling an

ordinary one-horse dump cart. This method is a great saver of labor where large quantities of clay are used, and where it can be kept in continuous operation; but most yards in Connecticut are too small to use a steam shovel with economy.

CONVEYING TO THE MACHINE.

Conveying the clay to the machine is usually done by horses and carts, or small cars, occasionally by cars hauled by cable, and, in one instance, by steam locomotive and cars. The chief influence on the method of carrying is the distance. If the machine is within a few hundred feet of the bank, carts are the most convenient, as two or three carts can supply the machine, and the cost of keeping them is not high. If the machine is farther away from the bank, more carts are needed to supply enough clay, and the cost of keeping the road in repair must also be considered. In many pits the roads are not properly cared for, and deep, uneven ruts are soon worn into the clay, making hauling more difficult, and wearing out both cart and horse in a relatively short time.

In such a case, both cost and labor could be saved by building a small track and hauling in cars. One horse can haul two cars more easily than one cart, and can return to haul two more while the first two are being dumped. Thus in yards of ordinary size only one horse is necessary to supply a sufficient amount of clay.

When the height of the machine above the pit is considerable, the most economical method of hauling is by cable, hauling the cars up an inclined track. If the distance is short, the cars may be hauled by cable all the way; if too great, as in older pits, the cars may be hauled to the foot of the incline by horses, and then up the incline by cable.

The steam locomotive, like the steam shovel, is adapted for large plants, where large quantities of clay are in constant demand and must be hauled over considerable distances, perhaps to several different parts of the plant. Only one plant in the state uses a locomotive.

PREPARATION OF CLAY FOR THE MACHINE.

In many cases the clay when mined is not fit for molding; it is either too hard, too coarse, too fine, too strong, or too lean,

PLATE VI. — DAVIS' CLAY PIT, QUINNIPIAC.

A good example of a well developed pit, showing benches at further end, and graded bottom, which allows water to collect in the right front corner, where the pump is located. Clay is overlain by a few feet of peat.

and needs some preparation, as crushing, soaking, or tempering, before it can be made into a good quality of brick. In some places, the clay when mined is hard and lumpy and is left to weather. The weathering breaks up the lumps and renders the clay more plastic and easily worked. Shale especially requires weathering before being worked. Stones in clays should be eliminated, and are best removed by passing the clay through a disintegrator, a pair of rollers which crush the clay lumps and small pebbles and throw out the larger ones. The final step in preparation is the tempering of the clay, or the mixing with it of other materials to give it the requisite stiffness to retain its shape when molded. The tempering material or "grog" depends upon the natural resources. Where strong and lean clays exist in the same pit, they are often mixed; burnt clay is sometimes used; but the most common grog is the sand which overlies the clay. This is much preferred to other grogs, as it diminishes shrinkage, and less of it is required. At Parkville and West Hartford, and in some parts of Berlin, there is little or no overlying sand, and sand has to be carted from some distance, or the thin coating of surface loam or quicksand is used. This loam is far inferior to sand, and makes a weaker mixture, which requires a light machine for molding. Coal dust is also added to the clay before molding, but not to temper it. It becomes disseminated through the bricks, and, during burning, serves to distribute the heat more uniformly through the brick.

The tempering is sometimes done in a tempering pit, but more often in the pug-mill of the machine. The tempering pit is circular in shape, with a post in the center around which a tempering wheel revolves by either horse or steam power. The Connecticut brick clays are all too fine and moist to require any preparation except tempering, and that is done by the machine; so the clay requires but one handling.

CHARGING THE CLAY INTO THE MACHINE.

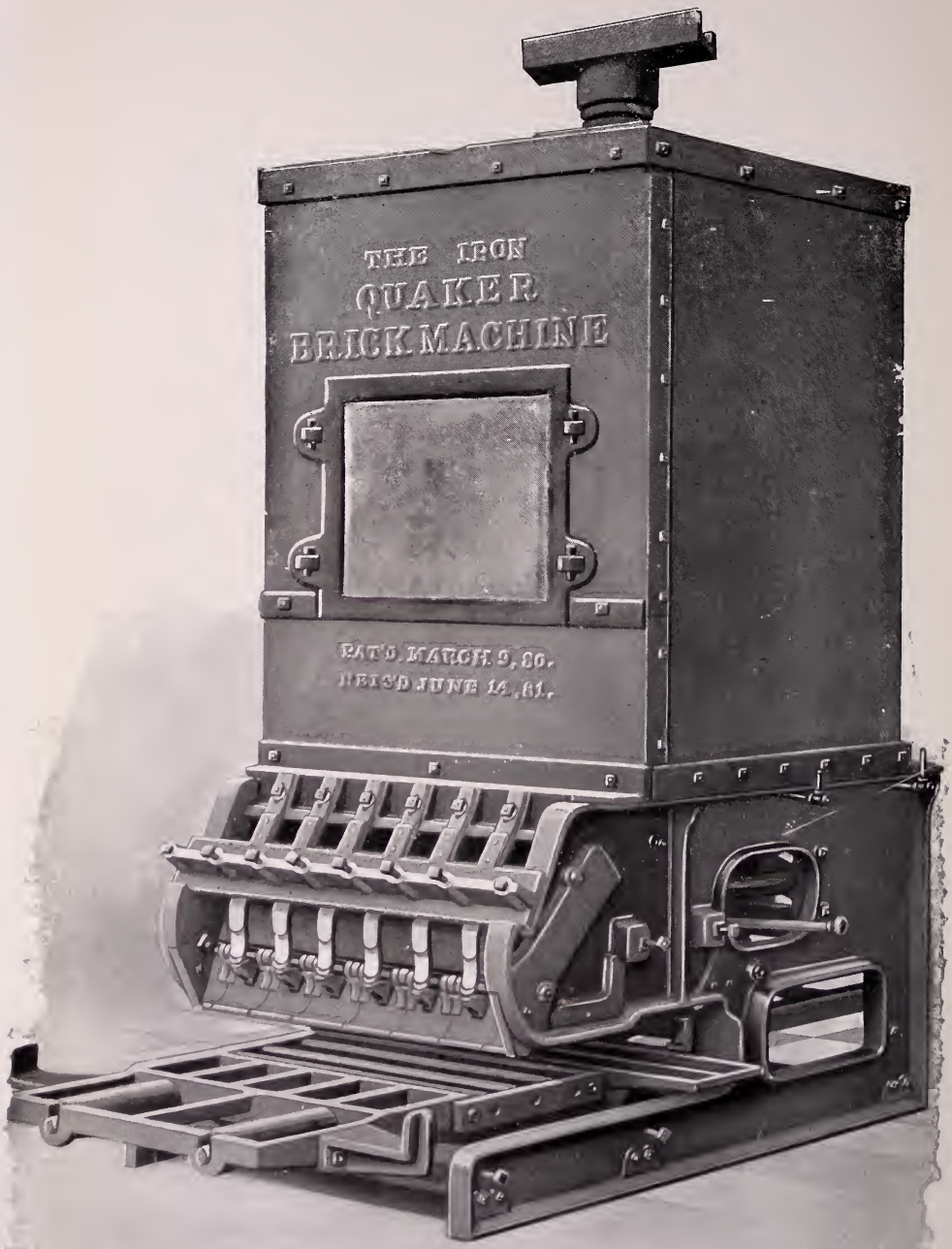
The material is charged into the top of the machine from a platform built over it, or by a clay elevator, which consists of an endless chain on sprocket wheels, carrying a series of buckets through a trough. The clay and sand are thrown

into the trough, taken along by the buckets, and dumped into the machine. Before the clay is dumped onto the platform, one-half the required amount of coal dust, usually three pecks to a thousand brick, or one peck to a load of clay, is spread over the floor. The grog is then added to the clay, the remaining half of the coal dust spread over the top of the heap, and the whole charged into the machine. The amount of grog varies with the clay: the strong clays require as much as one part of sand to two of clay, while the lean clays need no grog at all.

BRICK MACHINES.

Grinding and molding for common brick is done in Connecticut entirely by the "soft-mud" process, while a few yards, which manufacture hollow brick, use also the "stiff-mud" process.

Soft-mud Process. — The "soft-mud" process will be best understood by a general description of the "soft-mud" machine. There are several different types of machine, but all are modifications of the same general principle. The machine in general consists of three principal parts: first, the tub, horizontal or vertical, with knives projecting from the inner wall towards the middle, in which runs a shaft, also equipped with knives, and with a pair of wipers at its lower end; second, the press, which consists of a rectangular box on the front of the machine, in which a plunger moves vertically, pressing the clay into the molds; third, the table and appliances under the press box for holding the molds. The clay mixture is fed into the top of the tub, or, as is usually the case, into the disintegrator, and perhaps through an extra pug-mill, attached to the top of the machine, for removing pebbles and giving more thorough tempering. The material is then forced along through the tub by means of the knives and wipers into the press box. The descending plunger of the press forces and presses the clay into the mold, after which the mold is pushed out to the front of the table, while another mold slides under the plunger. This movement is made from the rear of the table by means of arms of the rock-shaft, not visible from the front of the machine. An empty mold is inserted in front of these arms, which, as the plunger rises, move


THE IRON
QUAKER
BRICK MACHINE
PAT'D. MARCH 9, 60.
REIS'D JUNE 14, 61.

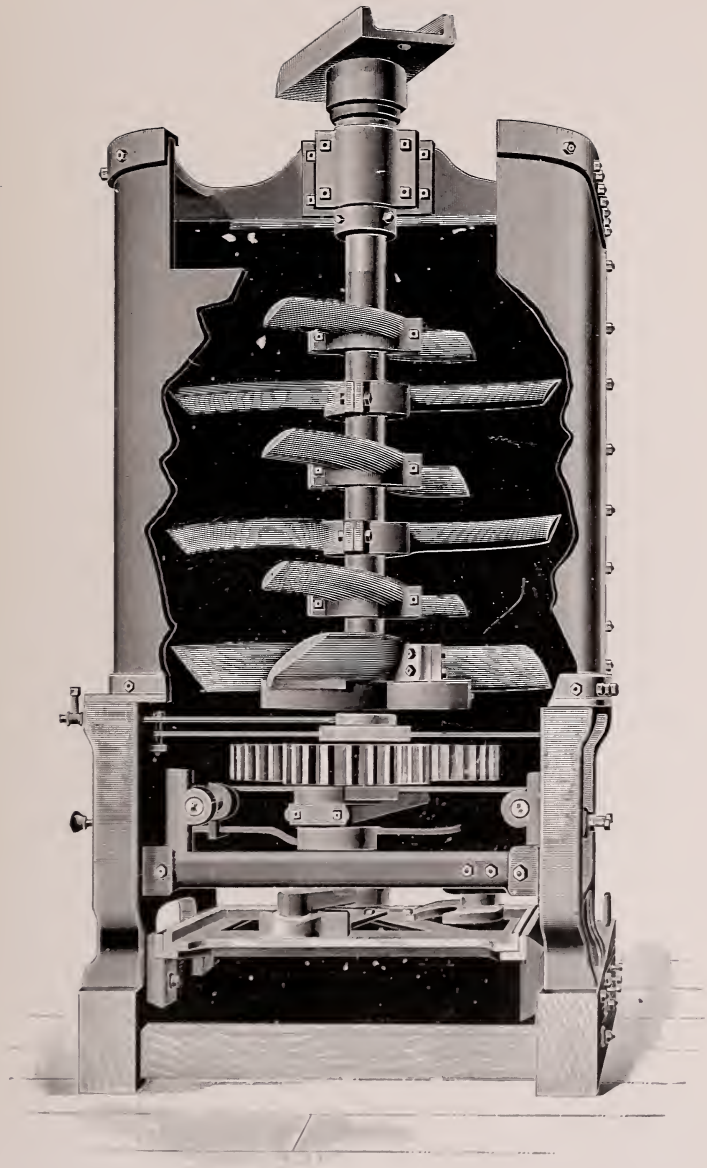
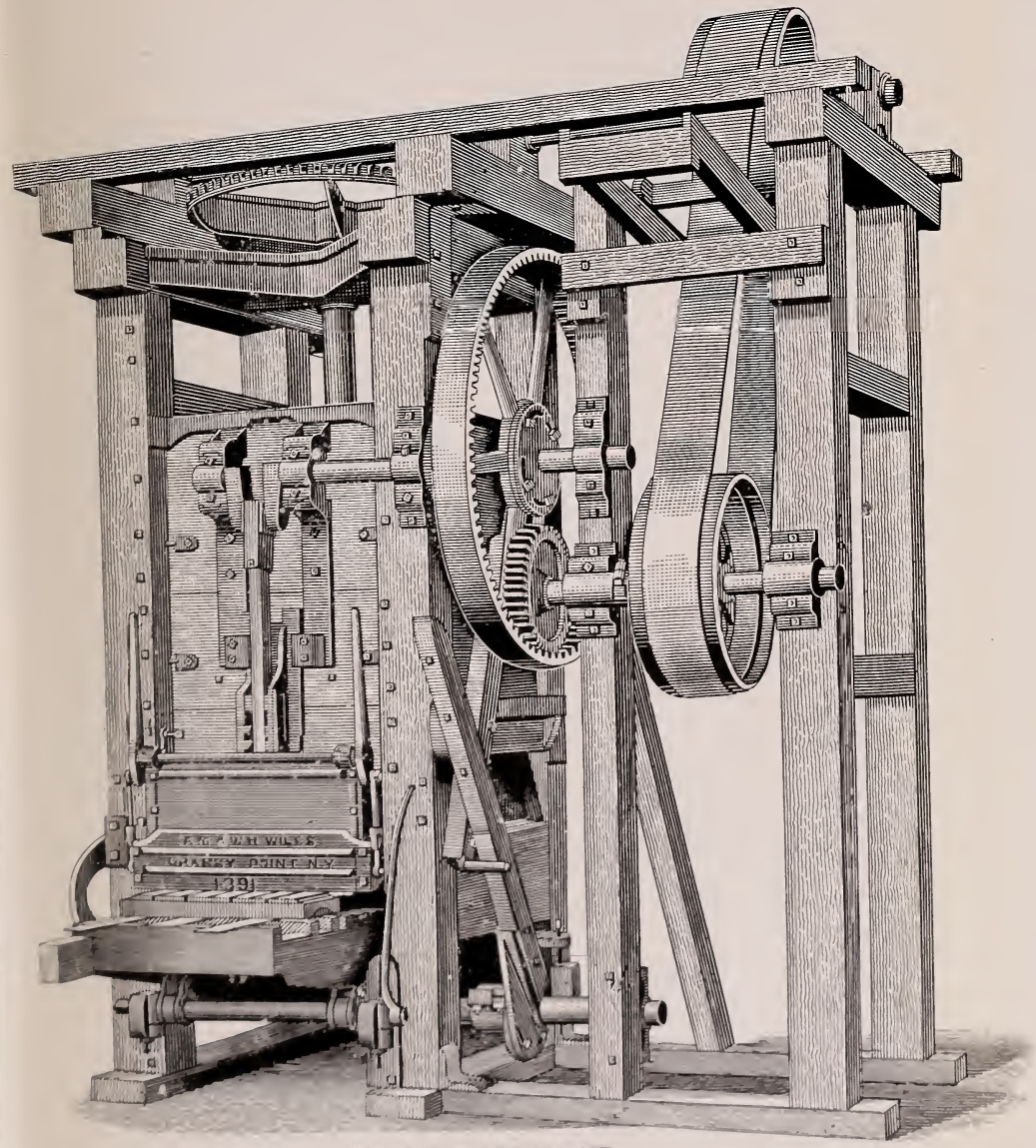


PLATE VII.—"IRON QUAKER" (HORSE-POWER) BRICK MACHINE.



H. MACHINE

PLATE VIII — A. M. & W. H. WILES "H" MACHINE

forward and push both the empty and the filled mold ahead of them to their respective places. On their return movement the rock-arms leave a gap into which the next mold is slid, and the process is repeated until the desired number of brick are molded. The backward and forward movement is effected by means of levers at the side of the machine, which are operated by cam rollers on the large vertical gear wheel.

The different types of machines are based practically on differences in the mechanical arrangement for driving the mud shaft and press, and for drawing out the filled mold. They range from light machines operated by horse power to large and heavy ones driven by steam or electric power. The larger machines temper the clay more thoroughly, use the clay in a drier condition, and press it harder; but they require more power to run. The size and power of the machine, then, depends principally on the stiffness of the clay, the size of the plant, and the choice of the individual brick-maker.

Plates VII, VIII, IX, and X show the varieties of soft-mud machines most commonly used in Connecticut. "The Iron Quaker" machine, plate VII, manufactured by the Wellington Machine Co. of Wellington, Ohio, represents a horse-power machine. It weighs 4,500 pounds, and makes 15,000 to 20,000 brick per day, with two horses and from five to seven men. It is six feet high, five and a half feet long, and three and a half feet wide. Five molds of six bricks each are turned out to every two turns of the horses. This machine is adapted for small yards.

The firm of A. M. and W. H. Wiles of Grassy Point, N. Y., has supplied machines for several of the smaller yards in the vicinity of Hartford. Plate VIII represents their "H" machine, which requires a ground area of ten feet by four feet seven inches. Its height from the center of the driving shaft to the base is twelve feet six inches; its weight is 15,000 pounds; the inside measurement of the tub is three feet five inches by three feet five inches; it is driven by steam and requires fifteen horse power; the line shaft is three and five-eighths inches in diameter, the mud shaft six inches, and the carriage shaft three and three-eighths inches. The latter is provided with slip joints to protect the carriage from break-

age, should anything get caught. The brick yards using the Wiles machines in 1903 averaged 20,000 to 21,000 brick per day.

Plate IX shows the style "B" machine, manufactured by the Henry Martin Brick Machine Manufacturing Company, Lancaster, Penn. It is used in some of the yards of the Quinnipiac area. In this machine the main upright, or tempering, shaft is extra heavy, and fitted with wrought-iron mixing knives; the crown gear is six inch face and two and a half inch pitch, with corresponding pinion; the spur gears are four inch face, the pinion being fitted with a friction clutch, allowing the machine to be started gradually and stopped instantly. The machine is equipped with an automatic mold protector, a friction relief, which prevents breakages in case a stone or other hard substance gets partly through the die and catches the mold, and an automatic self-strike, which cleans the tops of the molds as they come from beneath the press box. The machine weighs 8,000 pounds, is operated by steam, requiring ten horse-power, and has a daily capacity of 35,000 brick.

The three machines just described are all vertical machines. Maunfacturers emphasize the fact that in these machines gravity assists in feeding the clay towards the press box, thus avoiding the excessive wear caused by the necessity of requiring the tempering knives to force the material, and avoiding all end thrusts on the main shaft.

The largest and most commonly used machine in Connecticut is the "New Haven No. 2" machine, plate X, built by the Eastern Machinery Company of New Haven, Conn. This machine consists principally of a long, horizontal pug-mill, with a vertical press attached to the front end, into which the clay is forced by direct pressure. The mold-pusher, which rolls on a covered track in the mold table, is operated in connection with the large press gear, the whole being driven by one belt on the side of the machine, while the tempering shaft is driven independently with one pair of bevel gears at the rear. The pugging chamber is thirteen feet long, thirty-two inches wide, and thirty-four inches deep inside. One heavily-ribbed casting forms the rear end of the machine and also the bearing for the tempering shaft. The front end is formed by

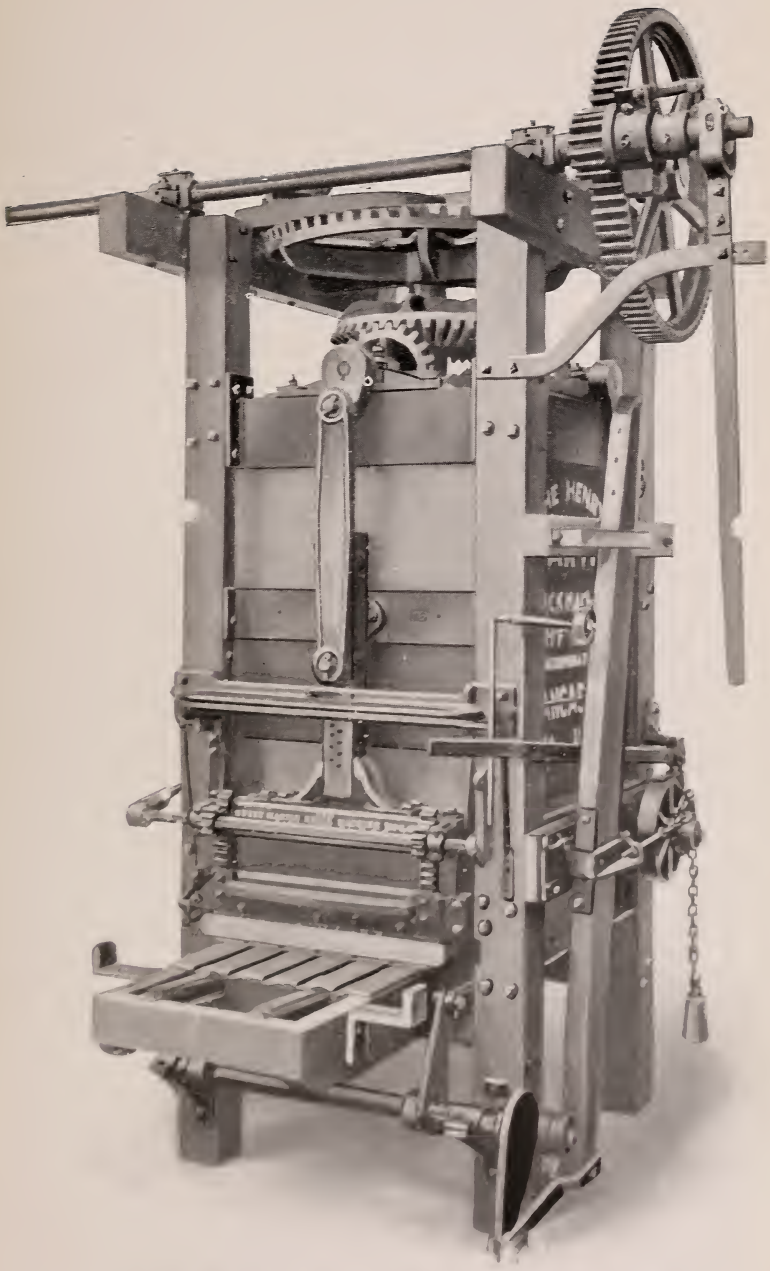


PLATE IX.—HENRY MARTIN "B" BRICK MACHINE.

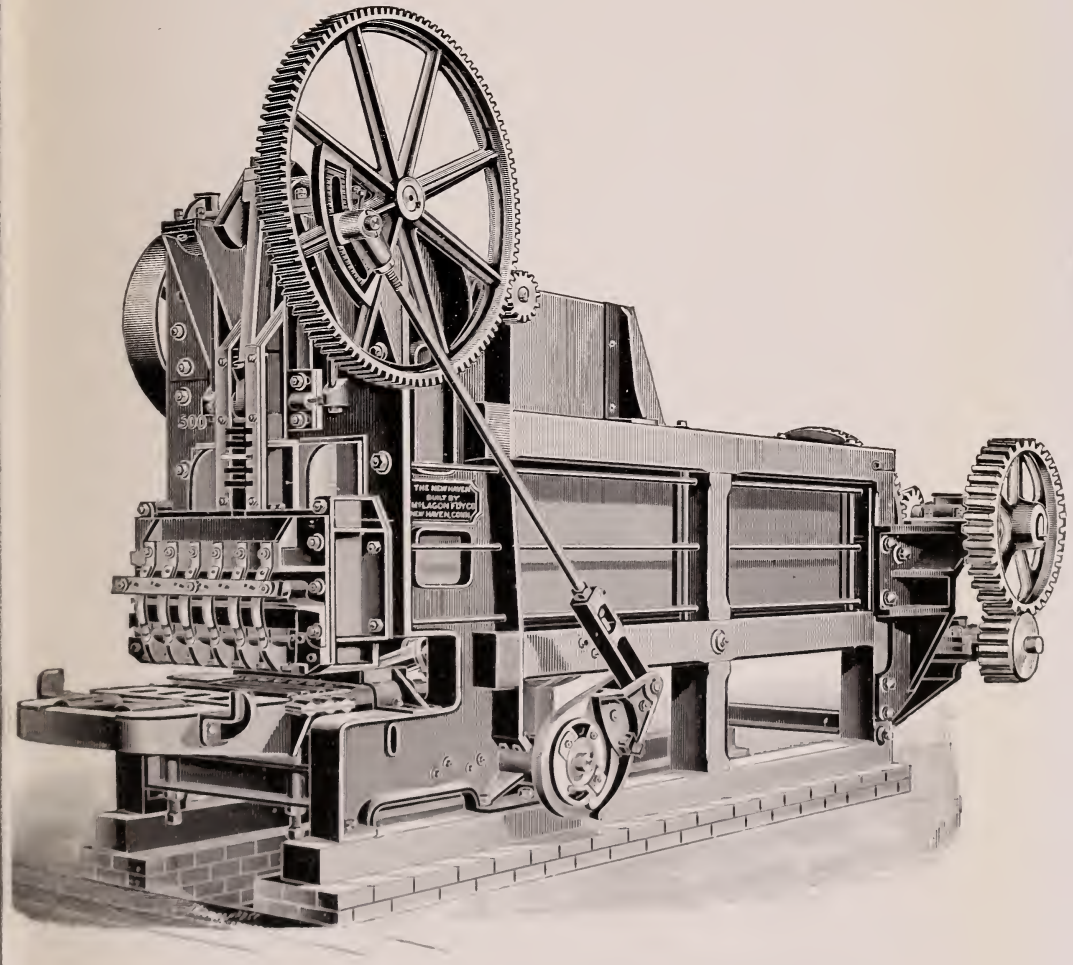


PLATE X.—NEW HAVEN No. 2 BRICK MACHINE.

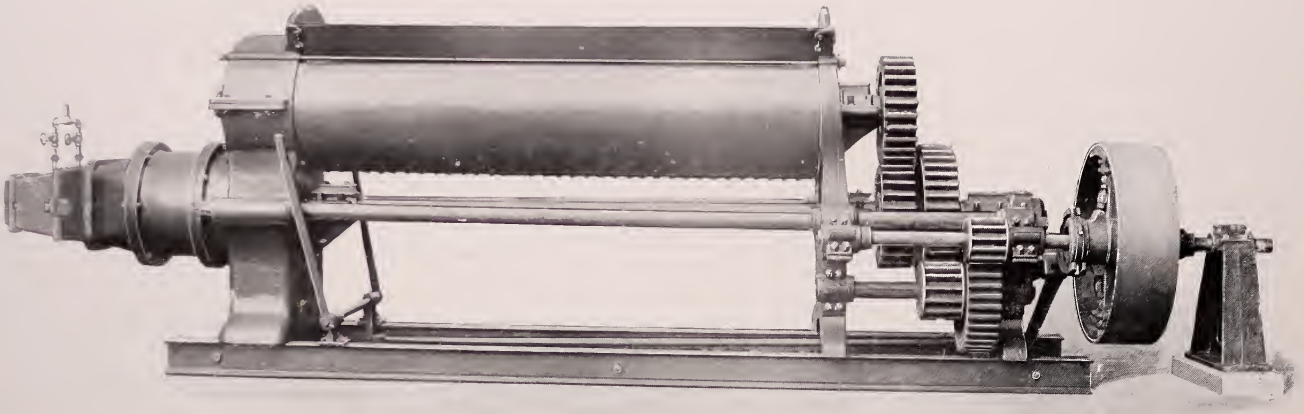


PLATE XI. — HENRY MARTIN "UNION" AUGER MACHINE.

two castings, of which the lower one supports the front end of the tempering shaft, while the upper one supports the steel press crank, and is secured against upward pressure of the press by heavy rods on each side of the crank pin. The whole front is held by the two side supports, which weigh over half a ton each. The advantage of the horizontal tub is that it is open at the top for its entire length, and enables the man who attends the tempering to see the exact condition of the clay until it enters the press, so that there is no reasonable excuse for not having the clay evenly tempered.

The vertical press is preferred to the horizontal or rotary presses, as it gives direct pressure and more power, thus filling all parts of the mold equally, and making bricks that will shrink uniformly during drying and burning. The press box is thirty-four inches long, ten and a half inches wide, and twenty-three inches deep, inside measurement. The unusually large depth permits extra space under the plunger for the clay to spread evenly and fill all the molds alike, while the direct pressure packs them solid.

The total weight of the machine is 17,300 pounds. It is operated by steam, or, in one instance, by electricity, and requires from twenty-five to forty horse-power, according to the quality and temper of the clay. The machine is adapted to work any clay, and its massive construction permits the working of the clay in a much stiffer condition with higher power than is possible with lighter machines. The capacity is ordinarily thirteen molds per minute, or 4,680 brick per hour. Most yards using this machine make from 45,000 to 46,000 brick per day of ten hours.

Stiff-mud Process. — The "stiff-mud" process is used in Connecticut chiefly for making a limited amount of hollow brick. The machine employed is called an auger machine, as the clay, after leaving the pugging chamber, is pushed through the die at the end by an auger. The die may be changed so that hollow brick, or front brick of different sizes, or tile may be made by one machine. The accompanying illustration, plate XI, of the Martin "Union" auger machine is sufficient to explain the working. The machine is made wholly of iron and steel; the pugging chamber is nine feet

long and two feet in diameter. It weighs 8,000 pounds, requires twenty-five horse power, and has a capacity of 20,000 to 30,000 brick per day.

The clay on emerging from the die is cut into the desired lengths by a wire, and so presents smooth surfaces, except on the ends. The chief disadvantage with auger machines is that the friction along the walls of the die retards movement of the clay, while in the middle it moves unhindered. As a result, the clay becomes laminated, and renders the brick liable to exfoliation.

Pressed-brick Process — Re-pressing brick is not carried on in Connecticut, although good pressed brick are said to have been made from Connecticut clays. Both soft-mud and stiff-mud brick may be re-pressed. In the dry press machine the clay is subjected to a very high pressure, and the resulting brick have very smooth edges and sharp corners. All clays do not work equally well in the press machine, as some crack when the pressure is released. Dry press methods, however, suit a great variety of clays, but require greater capital and equipment of plant, and a more thorough preparation of the clay.

MOLDING THE CLAY.

The manipulation of the molds in the soft-mud process is as follows: — The molds, each with six compartments, are first passed into a mold-sander — a trough in which are a series of revolving plates extending the full length, and in the bottom of which is placed fine sharp sand, dry and free from loamy matter. The molds are wet and placed on the revolving plates in such a way that the front edges of the plates, passing close to the wall of the trough, scoop up the sand, which slides over into the molds. As the mold comes up again, the surplus sand drops out. The mold is then tapped gently on the edge of the trough, jarring the still superfluous sand back into the machine, and is slid into the empty slot behind the press box. The fine sand, now coating the molds, permits the clay to slide easily from them. When the filled mold is pushed out onto the table, a man with a "brick-strike," or scraper, scrapes off the superfluous clay from the top. The mold is then taken

and dumped on a smooth, flat board or "pallet," which has been previously placed on a revolving dump table.

The revolving dump table is a wooden structure with four, five, or six leaves, on which the pallets are placed. The leaves work on spring hinges, and remain in a nearly vertical position until the newly molded brick are emptied onto the pallets, when they fall to horizontal. The bricks are carried half way around the circuit of the table, where the pallets are removed onto trucks.

Both the mold-sander and the dump table are usually connected by belts to the brick machine, so that all the machinery is operated by one engine and one main shaft. The dump table is so connected that it stops for every mold as it is sent out from the machine.

The trucks carry as many as nine pallets apiece. When a truck is loaded it is wheeled to the pallet racks, long covered rows of supports, on which the pallets are placed to dry. When the open-yard method for drying is employed, the molds are loaded directly onto the truck, and the brick emptied on the drying floor.

The whole process of molding is a continuous repetition and rotation of the molds, and varies slightly at different yards. The number of men necessary for the operation depends upon the size of the plant and the rapidity of molding. In yards using the "New Haven" machine the following number will easily make 45,000 pallet brick per day, at the rate of twelve to thirteen molds per minute: —

1 man to feed and temper the clay,
1 man to strike off the molds,
1 man to tend sander and feed molds,
2 men to dump brick on pallets,
3 men for truckers,
1 boy to wheel empty pallets to machine,
1 boy to place pallets on dump table,
1 boy to wash molds, etc.
Total, 9 men and 3 boys.

DRYING THE BRICK.

Two methods of drying are employed in Connecticut: the pallet system, and the open-yard. A third method, steam-drying, was attempted, but it did not prove successful.

The open-yard method is generally used at the smaller yards, where lighter machines are used; but several of the larger plants have small spaces reserved for open-yard drying. The open-yard method is adapted to clays that are not stiff enough to be molded in a heavy machine, or to retain their shape while slowly drying on the pallets. The brick are dumped from the molds onto a flat rolled surface, and left to dry in the sunlight. The sun's rays, striking more directly upon the upper part of the brick, evaporate the water more rapidly from the upper surface, and cause uneven shrinkage. Half a day of bright, uninterrupted sunlight will cause a marked difference in shrinkage between the top and bottom surfaces of the brick. After they have dried sufficiently, a man with a tool called an "edger" turns the brick, six at a time, onto their narrow surfaces. Another man follows with a "spatter," a flat board fastened perpendicularly to a long handle, and spats, or evens up the brick, by striking a vertical blow on the narrow, inclined surface, making it horizontal, and restoring the rectangular shape of the brick. Spatting requires a careful workman, as one misdirected blow will spoil six brick.

As soon as the spatted brick are dry enough to handle, they are "hacked," or piled on edge in single rows, about twenty brick high, each row resting on a row of planks, and covered by a wooden saddle, as shown in plate XII. These hacks are left to dry from four days to a week or more, according to the dry or moist condition of the air, and are then ready to be set in the kiln. In wet weather the hacks are protected by sheets of canvas hung along their sides. The chief disadvantage of the open-yard method is the danger of exposure to rain. An unexpected shower or a rain coming up in the night sometimes ruins a whole yard of brick. Excessive heat may, in some cases, cause cracking from too rapid shrinkage.

The pallet-and-rack system is decidedly superior to the open-yard, when the molded clay is sufficiently stiff. In this method, the pallets are set in tiers under long narrow roofs.

PLATE XII.—KANE'S BRICK YARD, PARKVILLE.

Shows plan of brick yard, using open-yard method of drying. Bricks are molded in machine at right front of picture, dried in yard, where they are seen in "hacks," and thence taken to the kilns under the shed at the rear.

Little or no sunlight reaches the brick, except on the end row, and the drying is accomplished by the circulating air. This circulation of air causes more rapid drying than takes place in the open yard, and the brick on the racks cannot draw up any moisture from the ground. As soon as the green brick are sufficiently stiff, they are edged, usually by hand, and left till ready for burning. Pallet brick usually require from four to seven days to dry, but in very wet weather they may require two weeks or more.

The roof and temporary shelters, which can be let down over the sides of the racks, protect the brick from rain and excessive heat, except in sudden storms, when the bricks in the end row may suffer before they can be covered. In case of frost, however, both open-yard and pallet brick suffer equally, as the water still in them bursts them by freezing. For this reason, the brick yards can be operated only between April and October, or during the season between the earliest and latest frosts.

The steam-drying process is more rapid and more expensive than the two preceding methods. There are several different types of steam, or hot air, driers which all present the same diffculty of the uniform circulation of heat throughout. This defect and the extra cost of fuel necessary to run them prevent their more extensive use. Their principal advantage is that they will dry the brick in any kind of weather, and require only one or two days to dry them sufficiently for burning.

BURNING THE BRICK.

All the brick in Connecticut are burned in temporary up-draft, or "scove" kilns. A few yards have used stationary up-draft kilns, but none were in use at the time of the writer's visit. The scove kilns are built of the green brick. Arches are built at the base for the fires, and the bricks above are set slightly apart so as to afford a circulation for the heat. Kilns are usually built about fifty brick high, and are erected under open sheds. The walls are of "double-coal" brick, containing a large amount of coal dust, which is supposed to draw the heat to the walls, and produce a uniform burn. Burned brick are often used with double-coal brick for the walls. The walls, when completed, are plastered with mud, making the kiln air-

tight on all four sides, and leaving the heat to escape at the top. The kiln walls are supported by strong frames, which prevent them from bulging out during the burning.

The only fuel used in Connecticut is wood. The fires are started very slowly, to evaporate out what included water still remains in the clay, and incidentally to give a more thorough oxidation to the iron. The temperature is then raised to red heat, and must be maintained at that temperature until the chemically combined water is expelled. The heat is then increased more rapidly, and kept at high temperature until the end of the burn, when the fires are allowed to die slowly down.[1]

Six to seven cords of wood are usually consumed in each arch, and the whole process of burning lasts about a week, or until the top of the kiln has settled a certain distance. This distance varies with the stiffness and degree of shrinkage of the clay; but, with the soft-mud brick of Connecticut, it is usually from ten to twelve inches, and is indicated by "tell-tales," or burned bricks hung from above so that they just touch the top of the unburned kiln.

The maximum heat in kilns of this type is obviously at the arches, and gradually diminishes towards the top; so, to give the uppermost bricks a thorough burning, the arch bricks must be greatly overburned, and are often found, after a burning, to have sagged, or even to have melted together. The exceedingly hot flame also has a reducing effect on the iron at the temperature of fusion, and produces the black color common to arch brick; though the black may be caused on the surface of an unfused brick by an insufficient supply of air, a smoky flame, or small particles of ash that fly up and stick to it.

The following figures, determined by Wheeler,[2] show the temperatures at which different colors are produced: —

The brick becomes

Dull salmon (at red heat)	1000° to 1200°F.
Deep salmon	1300° to 1400°F.
Light red (bright red heat)	1500° to 1600°F.
Deep red	1800° to 1900°F.
Very dark red (cherry red heat)	2000° to 2200°F.
Fuses and turns black at	2300°F.

[1] For details of behavior of clay during burning, see p. 48 in Part I.

[2] Mo. Geol. Surv., Vol. XI, 1896, p. 482.

Owing to the low fusing point of the Connecticut clays, these figures are undoubtedly high; but they serve to show the wide difference in the temperature through a kiln in which the top brick are only of salmon color, while the arch brick are fused. Such great difference in temperature is the great disadvantage of the scove kiln. A strong breeze blowing against one side of the kiln will cool the thin walls, and drive the heat to the other side, thus causing an uneven burn, while the very structure of the kiln makes uniform heating throughout impossible. The advantage of the scove kiln is that the burned brick may be left in the kiln till shipped.

The permanent up-draft kiln is built of burned brick, with solid walls on three sides, and with the fourth side open to facilitate removal of the brick after burning. The advantage claimed for the permanent up-draft kiln is that the bricks are more thoroughly and uniformly burned, a fact which should balance the extra cost of the kiln. Most manufacturers in Connecticut seem content with the temporary scove kiln, and the production of under-burned along with the well-burned brick. Only one permanent kiln stood in 1903, and that was not in use. It had been used for burning stiff-mud brick.

Down-draft kilns are not used in Connecticut at all for common brick manufacture. In these kilns the heat enters at the top, passes down through the stacked brick, and out through flues at the bottom. The fire does not reach the brick, and, it is claimed, can be more easily controlled so as to give a uniform heat.

REMARKS ON BURNED BRICK.

The dark red brick at or near the bottom of the scove kilns have undergone incipient, or in some cases almost complete, fusion, and become impervious; they are generally classed as sewer brick on account of their impervious character. The deeper colored brick are suitable for the outer walls of buildings, while the pale, under-burned brick should, on account of their high degree of porosity, be restricted to the inner parts of walls, out of contact with the atmosphere.

Many brick-makers do not separate the pale brick from the dark, and their sole object seems to be simply to sell the

brick. As a result, brick of several grades of quality are laid side by side in the faces of walls, and the difference in weathering after a few years is very noticeable. While the thoroughly burned bricks have suffered no visible change, the surfaces of paler brick have often become roughened, and the corners and edges have become rounded from disintegration due to weathering. The contrast is often enough to spoil a building's appearance.

In sidewalks the contrast in wearing under abrasion and weather combined is even more noticeable. While the black and dark red bricks show very little wearing, the pale colored bricks are worn into hollows which are often deep enough to render walking very uncomfortable, especially on rainy days, when each hollow becomes a puddle. For a sidewalk in a city, where hundreds of people pass every day, only the most thoroughly burned brick, such as sewer or black arch bricks, should be used, as by their partial or complete fusion, they practically fill the requirements for paving brick where the traffic is not too heavy. Pressed brick are better still, as their uniform color gives a better appearance; but their smooth surfaces are liable to make slippery walking in frosty weather.

Fancy brick are simply common or pressed brick molded into special shapes. They are used for ornamental work along with common building brick. Pressed and vitrified brick have been occasionally made from the local clays, but the demand for them is very small. Hollow brick are made by a few firms, but generally only to fill special orders. The hollow brick are used for fireproofing.

The principal loss in a burned kiln is the swelled bricks. The swelling has been explained in Part I as due to too rapid heating, without allowing sufficient time for drying, or for the escape of gases from coal dust, carbonates, or sulphates. Sometimes the swelling is due to the placing by mistake of undried or double-coal brick in the middle of the kiln. The black color commonly seen in swelled bricks is probably due to the reduction of the ferric oxide by the burning carbon. The carbon, unable to get oxygen from the air, has to take it from the iron, forming first carbon monoxide and finally the dioxide, leaving the black ferrous oxide in the brick. The

darker color of the inside of red bricks may be due to partial reduction of the iron by the coal dust.

MANUFACTURE OF FIRE-BRICK.

The fire-brick industry in Connecticut is limited to one firm, which manufactures fire-brick goods of all kinds — brick, stove and furnace linings, etc. The clays used are the Woodbridge and Raritan River clays of New Jersey. The tempering sand is taken mostly from New Jersey and Long Island. A little local sand is used; but, owing to its high percentage of silicates, it is hardly refractory enough for refractory ware, which should withstand a temperature of over 2,500° F.

A very great variety of goods is manufactured, and the company has on hand from 3,000 to 4,000 molds. The tempering is done by the soft-mud process, and the molding principally by hand, as the shapes of the goods are mostly such that they cannot be molded by machinery. The burning is done in a down-draft kiln, at a maximum temperature of 2,500° F. The plant has no regular capacity, but fills the various orders as they come.

CHAPTER III.

The Manufacture of Pottery.

The pottery industry in Connecticut is small. There is only one large firm, while two or three others do business on a small scale. Earthenware and stoneware are manufactured, the earthenware from native clay, the stoneware from New Jersey clays.

Earthenware. — The only large pottery plant in the state is engaged in the manufacture of plain and fancy earthenware. Common brick clay is used without mixture of other materials. After mining, it is soaked to a desired softness, and then put through a small grinding machine, in which a revolving vertical shaft with blades attached tempers the clay, and a screen at the bottom catches the stones. The clay is delivered at the bottom in sheets, which are then rolled up into balls and taken to the potters. These men shape the clay in molds revolving rapidly on potters' wheels. It requires but a few seconds for a skillful potter to mold the simpler articles. The filled molds are set on shelves to dry. The molds are made of plaster of Paris, to which the clay will not adhere, and which readily, and gradually, absorbs the moisture from the clay, so that in from half a day to a day the clay will have shrunk wholly away from the mold. The mold is then taken apart, and the green clay vessel is left to dry sufficiently before being set in the kiln.

The drying floor is in some cases situated over the kiln, and at night the floor is opened, admitting the heat, which hastens drying. At some potteries the ware is dried over steam or hot air pipes.

If the clay is too moist when burned, it explodes, and, if burned too long, it vitrifies and sags, ruining the ware. The burning generally lasts for two days. The down-draft kiln is generally used, and both coal and wood may be used for fuel.

After burning, the fancy ware is sent to be decorated. The

decorating is all done by hand, and, with the molds of various shapes, produces an endless variety of goods.

Stoneware. — There is only one firm in the state which manufactures stoneware. The South Amboy clays of New Jersey are used. The process of molding is principally by hand, as the shapes of the goods are such that molds cannot be conveniently used. The clay is placed on a revolving disc, or wheel, and the potter, by "feeling" the clay, that is, by working it into a position where its natural tendency to slump on account of its plasticity is just balanced by the centrifugal force generated by the rotation, brings it to the desired shape.

Different mixtures of clay are used for different kinds of ware. The dark glaze on the interior of the ware is produced by a slip clay from Albany, N. Y. The clay is made into a thin paste, and sprayed over the inner surface of the ware by a force pump. Its relatively low and rapid fusion causes it to melt and soak into the pores of the stoneware clay, making an impervious body. The glaze on the outer surface is produced by common salt, which is put into the top of the kiln, melts, and runs down over the surfaces, uniting with silica and forming the glaze. The chlorine gas from the salt is driven off at the top of the kiln. The maximum temperature in burning is somewhere above 2,000° and below 2,500° F., as the liquid fusion of the slip probably cannot take place much below 2,000°, and the heat at 2,500° is so great as to cause the slip to begin to vaporize, and ruin the glaze.

Products no Longer Manufactured. — There formerly was a manufactory of white ware at New Milford, but it has not been operated since 1903. Drain tile and sewer pipe also have been formerly manufactured at several localities, but both industries, as far as the use of clay is concerned, have been idle for some years.

CHAPTER IV.

The Condition of the Clay Industries of Connecticut.

The abundance and similarity of the brick clays in Connecticut, and the small profit made on clay products, limit the location of plants either to areas where a railroad crosses a clay area, and shipment can be made directly from the kiln to the freight cars (Plate XIII), or to the neighborhood of the large cities, which can consume the output. For this reason, many square miles of good clay deposits in the rural parts of the state are untouched.

The general tendency of the brick-makers seems to be to cling to the old, often unprofitable methods of manufacture, rather than to investigate and attempt improvements of any kind. Improvements have been attempted in a few cases unsuccessfully, and these failures, along with lack of capital, may account for the present lack of enterprise. The quality of the clay is such as to encourage improvements; and success in attempted improvements then depends partly upon the quality of the apparatus, but principally on the skill and judgment of the clay worker.

Some brick-makers prefer to employ unskilled labor, which they can turn to any kind of work at low wages, rather than to employ skilled labor at greater expense for the special work that some improvements would require. Such facts are important, especially in yards of not very great capacity; but improvements, especially in the quality of brick produced, may lead to enlargement of the plant. No improvements can be made without experiments and expenditure of time and capital, and the returns will not follow immediately, but will probably increase after they begin. The native clay is certainly capable of turning out a better quality of brick than is made today, if more care is taken in the tempering and burning. The large percentage of under-burned brick that are sold with

PLATE XIII.—KILN SHEDS BELONGING TO SHARES' BRICK YARD, QUINNIPIAC.

Spur track runs under the sheds, and bricks are loaded directly into freight cars.

well-burned brick must obviously detract from the quality of the brick as a whole. Unless the builders prefer to use poor brick at low cost, there is no reason why the quality of brick should not be raised even at an increase of cost.

The chief difficulty with the manufacture of any other than common brick on an extensive scale is that the output of other states already supplies the market. It is very probable that the Connecticut clays can make good pressed and vitrified brick, but they cannot compete with the reputation already established in other states. But, here again, no reputation can be made without a considerable expenditure of time and money.

STATISTICS OF THE CLAY INDUSTRIES.

The following tables of the brick and pottery maunfacturers will give a general idea of the extent of the clay industries in the state:

BRICK MANUFACTURERS.

Locality and Name of Manufacturer.	Number of Men Employed.	Capacity (Brick per day).	Varieties Manufactured.	Method of drying.	Kind of Power.
Thompsonvile Dist.					
Alden's.....	21	22,000	Common	Pallets	Steam
Windsor Dist.					
Wilson's.....	(av.) 38	44,000	Common	Pallets	Steam
Baker's	5	10,000	Common	Pallets and open yard	Horse
Curtis'.....	(Not running in 1903.)		Common and hollow		Steam
Mills & Son's.....	12	20,000	Common	Open yard	Steam
March's.....	5	12,500	Common	Open yard	Steam
So. Windsor Dist.					
E. Windsor Hill Brick Co.'s.....	40	45,000	Common	Pallets	Steam
Meed & Mullaly's.	16	20,000	Common	Open yard	Steam
Parkville Dist.					
Kane's.....	20	21,000	Common	Open yard and pallets	Steam
Dorr's.....	20	21,000	Common	Open yard and pallets	Steam
Electric B. Co.'s..	20	21,000	Common	Open yard and pallets	Steam
Dennis's	(Not running in 1903.)				
Elmwood Dist.					Steam
Park B. Co.'s	45	45,000	Common	Pallets and open yard	Electricity
Hartford B. Co.'s.	40	45,000	Common	Pallets	
Clayton Dist.					
New Britain B. Co.'s.....	35	46,000	Common	Pallets	Steam
Dennison's.....	(No information received.)				
Berlin Dist.					Steam
Murray's.....	53	46,000	Common	Pallets	Steam
Berlin B. Co.'s....	48	46,000	Common	Pallets	Steam
Towns Bros.'.....	48	46,500	Common	Pallets	Steam
Donnelly's.....	46	46,000	Common	Pallets	Steam
Merwyn's.....	90	90,000	Common and hollow	Pallets	Steam
Standard B. Co.'s.	45	47,000	Common	Pallets	Steam
W. L. Davis'.....	54	47,000	Common and hollow	Pallets	
Holmes'	(No information received.)				Steam
American B. Co.'s	47	47,000	Common	Pallets	
Middletown Dist.					
Clark's	(Not running in 1903.)				
Tuttle's.....	(No information received.)				
Johnson's	35	40,000	Common	Pallets	Steam

BRICK MANUFACTURERS — *Continued.*

Locality and Name of Manufacturer.	Number of Men Employed.	Capacity (Brick per day).	Varieties Manufactured.	Method of drying.	Kind of Power.
Quinnipiac Dist.					
Stiles & Son's [1]...	200	150,000	Common	Pallets	Steam
Brockett's.....	(No information received.)				
Share's [1].....	80	85,000	Common	Pallets	Steam
W. E. Davis' [1]....	50	70,000	Common	Pallets	Steam
Milldale					
Clark Bros.'.....	18	20,000 [3]	Common	Pallets	Steam
Total.....	1,131 [2]	1,153,000 [2]	.....	.....	.....

Average wages per day, $1.00 to $2.00. Length of day, ten hours.

The only firm manufacturing fire-brick is that of Howard and Company, New Haven.

Only two operating firms producing pottery furnished any data. These two firms are: Goodwin Bros., Elmwood, 40 men, plain and fancy earthenware; John O'Halloran, New Haven, 7 men, earthenware and stoneware.

The value of the clay products of Connecticut from 1894 to 1903, inclusive, is shown in the following table, compiled from the United States Geological Survey's annual report on the Mineral Resources of the United States. The amount in the table contributed by Rhode Island is not enough to alter the significance of the figures:

[1] Operates two yards.

[2] Yards not reported aggregate a little over 100 men, and about 135,000 brick per day.

[3] Not steadily operated.

CLAY PRODUCTS OF CONNECTICUT AND RHODE ISLAND, 1894–1903.

Product.	Year.									
	1894[d]	1895[d]	1896[d]	1897	1898	1899	1900	1901	1902	1903
BRICK										
Common										
Quantity	100,300,000	18,550,000	166,995,000	200,130,000	120,380,000	150,665,000	164,431,000	160,696,000	156,885,000	158,382,000
Value	$549,650	$642,462	$996,738	$1,017,250	$670,880	$751,239	$862,334	$822,079	$896,171	$890,989
Average per M	$5.48	$5.41	$5.79	$5.00	$5.57	$4.99	$5.24	$5.12	$5.71	$5.62
Pressed										
Quantity		150,000	90,000	3,200,000	*a*	*a*	*a*	*a*	*a*	*a*
Value		$4,500	$1,900	$89,400	*a*	*a*	*a*	*a*	*a*	*a*
Average per M		$30.00	$21.11	$27.93	$15.37	$8.78	$15.02	$15.04	$9.09	$15.04
Vitrified										
Quantity	10,000	.....	20,000	4,015,000	*a*	*a*	*a*	.....	*a*	*a*
Value	$250,000	.....	$400	$50,270	*a*	*a*	*a*	.....	*a*	*a*
Average per M	$25.00	.....	$20.00	$12.52	$12.58	$10.00	$12.00	.....	$9.10	$14.03
Fancy or Ornamental										
Value	$5,000	$600	.....	$16,500	*a*	*a*	*a*	*a*	*a*	*a*
Fire										
Value	$57,000	$64,000	$71,800	$44,750	*a*	*a*	*a*	*a*	*a*	$61,500
STOVE LININGS										
Value	.....	.....	.....	.....	*b*	*a*	.....	*a*	$12,750	
DRAIN TILE										
Value	$500	$1,000	$14,100	$1,000	.....	.....	*a*	.....	.....	.....

SEWER PIPE Value	$15,000	$4,500	$2,460	.....	.....	.....	*a*	.....	.....	.....
FIREPROOFING Value	.....	.....	$500	$21,000	*a*	*a*	*a*	*a*	*a*	*a*
TILE (not drain) Value	$5,000	.....	$15,000	$15,000	*a*	.....	*a*	.....	.....	.....
ORNAMENTAL TERRA COTTA Value	$60,100	$44,563	$30,000	$10,000	.....	.....	.....	.....	.....	.....
POTTERY Earthenware and Stoneware Value	.....	$2,800	$33,460 $13,240	$71,500	$16,100	$53,250	$44,250	$48,200	$48,100	$42,250
Miscellaneous[c] Value	$24,000	$67,500	$2,000[c]	.....	$261,200	$269,713	$193,388	$260,630	$260,657	$211,330
Total value	$717,000	$831,925	$1,119,920	$1,336,670	$948,180	$1,074,202	$1,099,972	$1,130,909	$1,217,678	$1,206,069
Number of firms operating..	44	44	47	.....	48	45	47	45	41	41
Rank of Conn. and R. I.....	19[d]	20[d]	11[d]	10	16	20	20	2[illegible]	21	23

a Included in miscellaneous.
b Stove lining not separately classified until 1899.
[c] Includes all products not otherwise classified, and those made by less than three producers, in order that the operations of individual establishments may not be disclosed.
[d] Rank of Connecticut alone.
[e] Porcelain and china.

These values show a continual fluctuation in the past nine years. The most profitable year was 1897, and was followed by a considerable slump in 1898. Then followed a steady increase up to 1902, while 1903 shows a decline of $11,609, which is confined to the pottery and miscellaneous. But, while the total value of clay products in Connecticut has remained fairly steady, about $1,000,000, those of other states have been steadily increasing, so that, while in 1896 Connecticut alone ranked eleventh in the United States, in 1903 Connecticut and Rhode Island together rank only twenty-third. The advance of the western states is due to the formation of large, well capitalized companies, which can employ chemists and other men with professional training to experiment with their materials and determine accurately what processes and mixtures will give the best results and at what temperatures; and until manufacturers, even of common brick, establish more thorough and careful methods, they cannot compete with the western states. Connecticut has the materials, but needs more careful methods of manufacture and a market for goods of better quality.

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